REPORT No. 904

ESTIMATION OF F-3 AND F-4 KNOCK-LIMITED PERFORMANCE RATINGS FOR TERNARY AND QUATERNARY BLENDS CONTAINING TRIPTANE OR OTHER HIGH-ANTIKNOCK AVIATION-FUEL BLENDING AGENTS

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SUMMARY

Charts are presented that permit the estimation of F-3 and F-4 knock-limited performance ratings for certain ternary and quaternary fuel blends. Ratings for various ternary and quarternary blends estimated from these charts compare favorably with experimental F-3 and F-4 ratings. Because of the unusual behavior of some of the aromatic blends in the F-3 engine, the charts for aromatic-paraffinic blends are probably less accurate than the charts for purely paraffinic blends.

INTRODUCTION

An investigation of the knock-limited performance of triptane and other high-antiknock components of aviation fuels was conducted at the NACA Cleveland laboratory in the F-3 and the F-4 rating engines (reference 1). The data of reference 1 are presented herein in the form of charts, which can be used to estimate the F-3 and the F-4 antiknock ratings for multicomponent blends of the various fuels investigated.

The F-4 data appearing in these charts are based on the following blending equation suggested in reference 2 for supercharged-engine data:

$$\frac{1}{\text{imep}} = \frac{N_1}{(\text{imep})_1} + \frac{N_2}{(\text{imep})_2} + \frac{N_3}{(\text{imep})_3} + \cdots \quad (1)$$

where

imep	knock-limited indicated mean effective pressure of fuel blend
$(\text{imep})_1$, $(\text{imep})_2$, $(\text{imep})_3$, ...	knock-limited indicated mean effective pressure of components 1, 2, 3, ...
N_1, N_2, N_3, ...	mass fractions of components 1, 2, 3, ... in fuel blend

Equation (1) has been satisfactory for blends in which all components are paraffinic and have equal concentrations of tetraethyl lead. The equation applies most generally when the experimental data are taken at high fuel-air ratios. With the exception of data for one fuel in the present analysis, all the F-4 knock-limited performance data are considered at a fuel-air ratio of 0.11.

The analysis of F-3 data presented herein is strictly empirical but has been found to agree satisfactorily in most cases with the experimental data. The accuracy of the performance charts presented was checked by testing prepared blends under F-3 and F-4 conditions and comparing the observed ratings with those predicted from the charts.

EXPERIMENTAL DATA

The experimental results upon which this analysis is based are presented in table I (reproduced from reference 1). No performance numbers in this table greater than 161 were used in this analysis, as will be indicated later. The performance numbers for the F-4 tests were estimated from a reference-fuel framework (reference 1) consisting of knock-limited performance curves for 90-percent S-3 reference fuel plus 10-percent M-4 reference fuel and for S-3 reference fuel clear and with 0.5, 1.25, 2, 4, and 6 ml TEL per gallon.

The use of this method of rating instead of the usual procedure of direct matching was necessary because of the extensive nature of the program; complete mixture-response curves for 132 blends were obtained. For this reason, the accuracy of the performance numbers shown in table I for F-4 ratings is largely dependent on the day-to-day reproducibility of the engine. The brief analysis of the results given in reference 1 indicates that this reproducibility is good at high fuel-air ratios. Inasmuch as the analysis herein is concerned only with data at a fuel-air ratio of 0.11, it is believed that the performance-number ratings at this fuel-air ratio are reasonably accurate.

All blends investigated were prepared on a volume basis.

PREPARATION OF PERFORMANCE CHARTS

In order to make the final charts useful for the prediction of blends giving F-4 performance numbers greater than 161 at a fuel-air ratio of 0.11, it was considered desirable to extrapolate the performance curve to at least a performance number of 200. This extrapolation was made by plotting the performance numbers against knock-limited indicated mean effective pressure from the reference-fuel framework in reference 1. (See fig. 1.) Although there is a definite break in this curve at a performance number of 130, the curve appears to be linear between 130 and 161. On the assumption that this linear relation is true, a straight line was drawn through the points at 130 and 161 and extended to a performance number of 200. The extrapolation between

225

161 and 200 is shown as a broken line in figure 1. In refer-
ence 1, a different method of extrapolation was used for
performance numbers greater than 161 (fig. 1); consequently,
the performance-number values above 161 in table I for
F-4 ratings are not the same as those used in preparing the
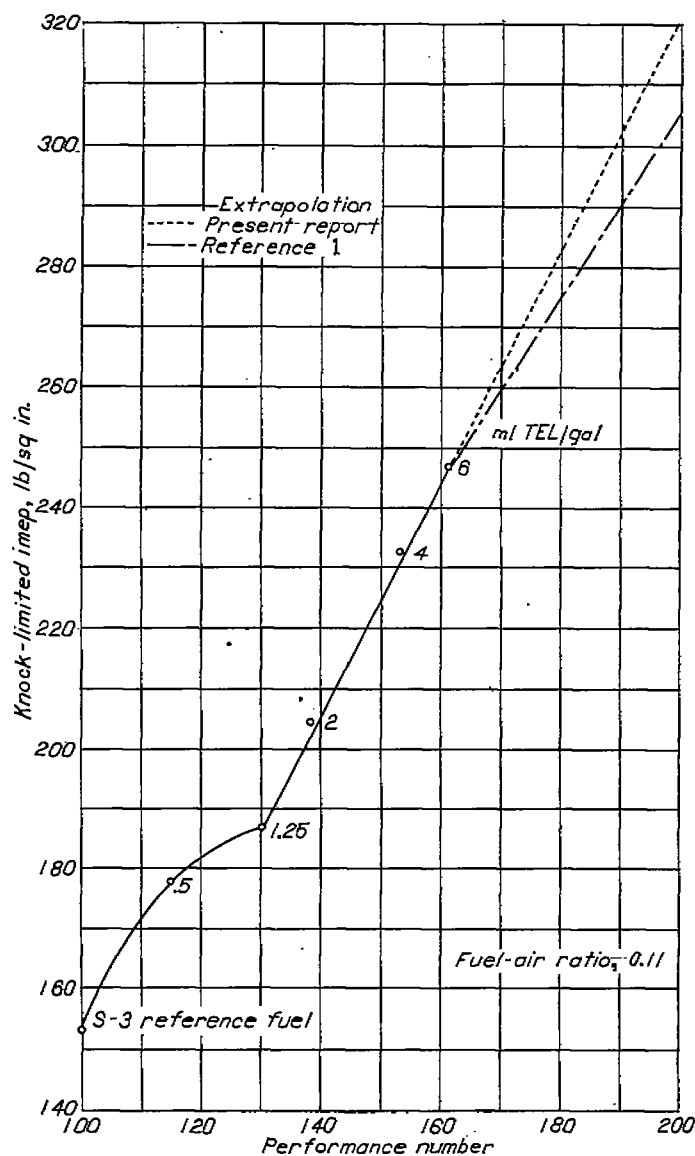performance charts in the present report.

FIGURE 1.—Relation between performance numbers and knock-limited indicated mean
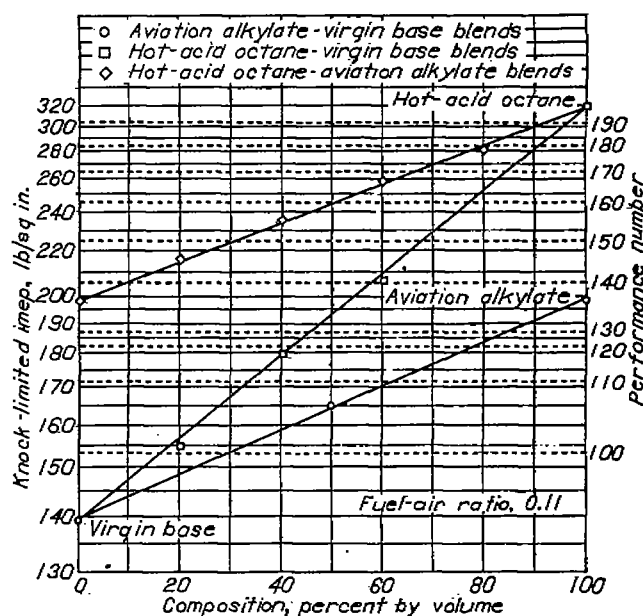effective pressures as determined in F-4 rating engine.

FIGURE 2.—Knock-limited performance determined by F-4 rating method for binary blends
of hot-acid octane, aviation alkylate, and virgin base stock. All blends contain 4 ml TEL
per gallon.

TERNARY BLENDS

As an example of the preparation of a performance chart,
first it is desired to know the F-3 and the F-4 performance
numbers of all possible ternary blends of hot-acid octane, an
aviation alkylate, and a virgin base stock. These three
fuels were chosen because their blending relations follow
equation (1). A plot of composition against the reciprocal
of the knock-limited indicated mean effective pressure for
binary blends of any two of these fuels will result in a straight
line. The three binary combinations of these materials
are shown in figure 2. The ordinate scale of this figure is a
reciprocal scale used for convenience in order that the in-
dicated mean effective pressures can be plotted directly.
Experimental data for figure 2 were taken from table I.

In the next operation, lines of constant performance
number are drawn on the plot (shown as dotted lines, fig. 2).
These lines are established by reading values of indicated
mean effective pressure at equal increments of performance
number in figure 1. The data as shown in figure 2 are the
basic information needed to establish F-4 rating lines on the
final chart for multicomponent blends.

For convenience in relating composition and knock-
limited performance of ternary fuel blends, all performance
charts are prepared on triangular coordinate paper. A
brief description of the use of triangular coordinate paper is
given in the appendix. A more detailed description of
triangular plots is given in reference 3.

The performance chart for the system of hot-acid octane,
aviation alkylate, and virgin base stock is shown in figure 3.
Lines of constant performance number in this figure were
determined by noting the intersections of the constant per-
formance lines (fig. 2) with the blending lines. For example,
the 150-performance-number line in figure 2 intersects the
blending line of hot-acid octane and aviation alkylate at a
composition of 32-percent hot-acid octane and 68-percent
alkylate and intersects the blending line of hot-acid octane
and virgin base stock at a composition of 67-percent hot-acid
octane and 33-percent virgin base stock. These two com-
positions were plotted on figure 3 and joined by a straight
line. Any point on this line represents a blend of hot-acid
octane, alkylate, and virgin base stock that will give a
performance number of 150 in the F-4 engine at a fuel-air
ratio of 0.11. All performance lines in figure 3 were es-
tablished in this manner.

The lines in figure 3 are parallel, which is to be expected
when the curves shown in figure 2 are linear. On the basis
of data in this report and in references 4 and 5, it appears
that most paraffinic fuels blend linearly at high fuel-air
ratios. Even though certain constituents such as the aro-
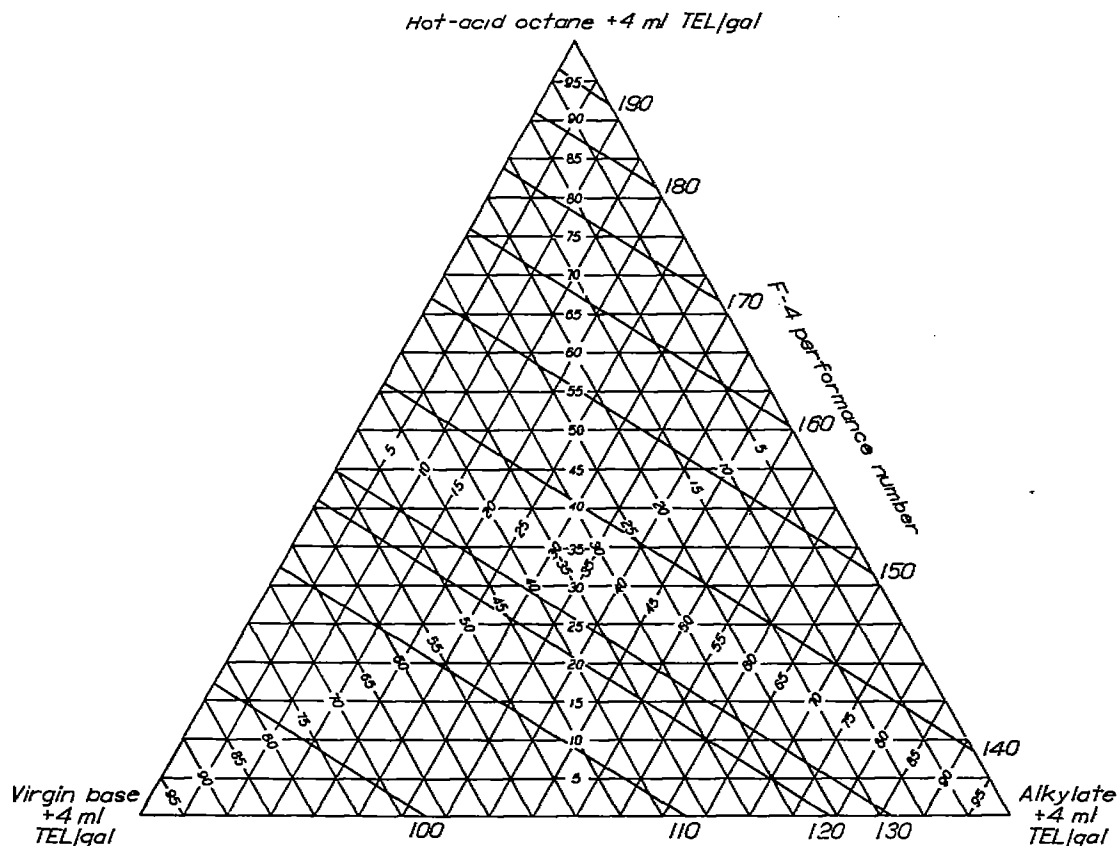matics or ethers did not blend linearly with paraffinic base

FIGURE 3.—Knock-limited performance determined by F-4 rating method for ternary blends containing hot-acid octane, aviation alkylate, and virgin base stock.
F-4 ratings at fuel-air ratio of 0.11.

fuels, the procedure just outlined for the preparation of performance-number charts is not altered. A nonlinear relation in a plot of the type shown in figure 2 results in a variation of slope with performance number on the final triangular plot.

The procedure used for determining the lines of constant F-3 performance for blends of the same fuels used in preparing figure 3 differs from that used for F-4 performance in that performance numbers are plotted directly against composition on linear coordinate paper and an estimated "best" curve is drawn through the data points to determine the binary blending relations shown in figure 4. There is nothing to justify the use of this empirical method for dealing with F-3 ratings except that the end result agrees reasonably well with the experimental results. One or two exceptions to this method will be pointed out later.

The compositions at the intersections of a given constant performance line with the blending lines (fig. 4) were plotted on triangular coordinate paper and joined by straight lines. The resulting F-3 performance lines are shown in figure 5. The final chart (fig. 6) was obtained by superimposing figure 5 on figure 3. Performance charts for the following fuel constituents blended with aviation alkylate and virgin base stock (all blends leaded to 4 ml TEL/gal) were prepared in the same manner and are presented in figure 7: triptane, diisopropyl, neohexane, isopentane, benzene, cumene, mixed xylenes, toluene, and methyl tert-butyl ether. Charts for hot-acid octane, triptane, diisopropyl, neohexane, isopentane,
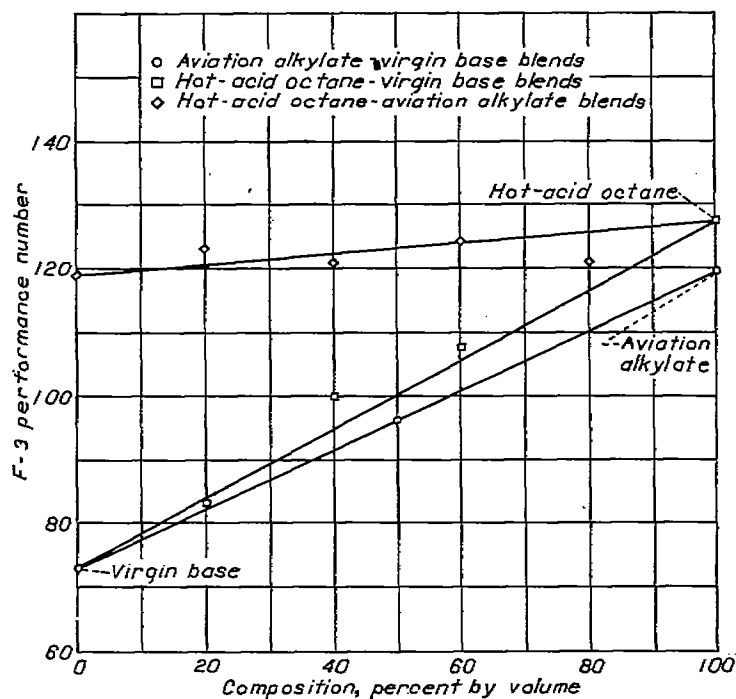
FIGURE 4.—Knock-limited performance determined by F-3 rating method for binary blends of hot-acid octane, aviation alkylate, and virgin base stock. All blends contain 4 ml TEL per gallon.

benzene, mixed xylenes, toluene, and methyl tert-butyl ether blended with aviation alkylate and one-pass catalytic stock are presented in figure 8.
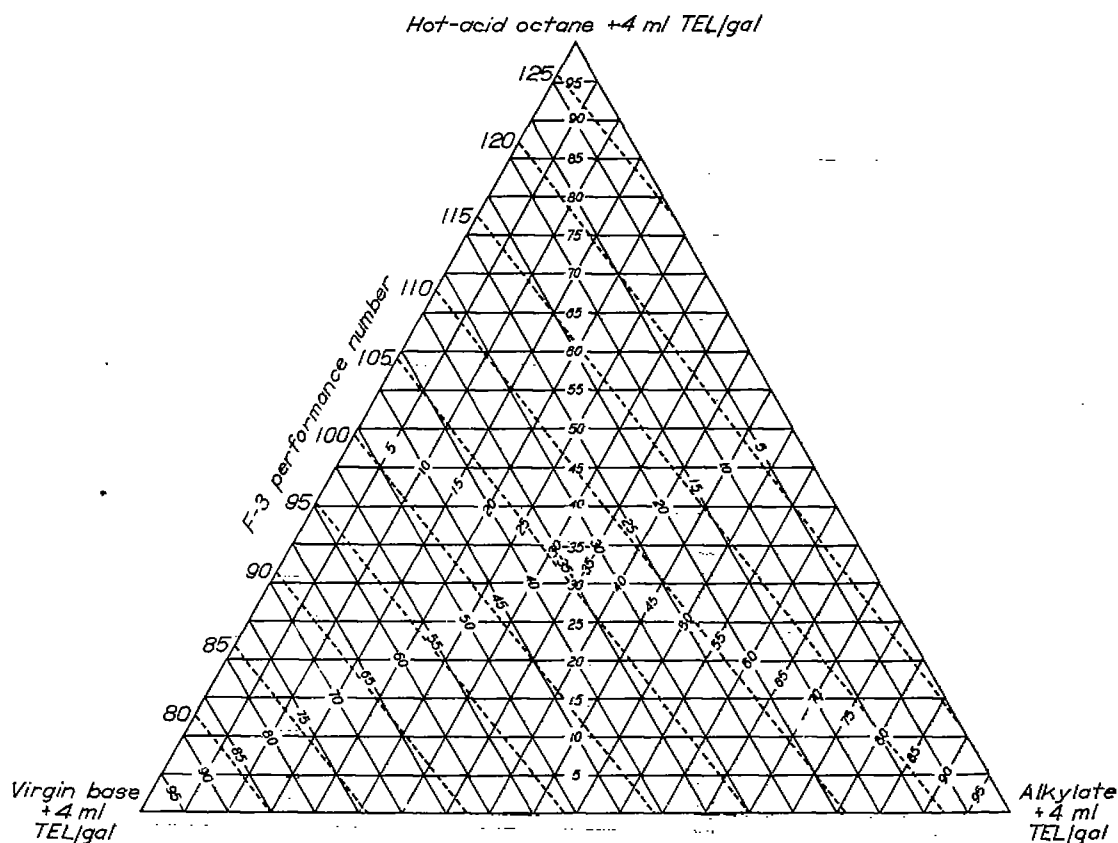
FIGURE 5.—Knock-limited performance determined by F-3 rating method for ternary blends containing hot-acid octane, aviation alkylate, and virgin base stock.
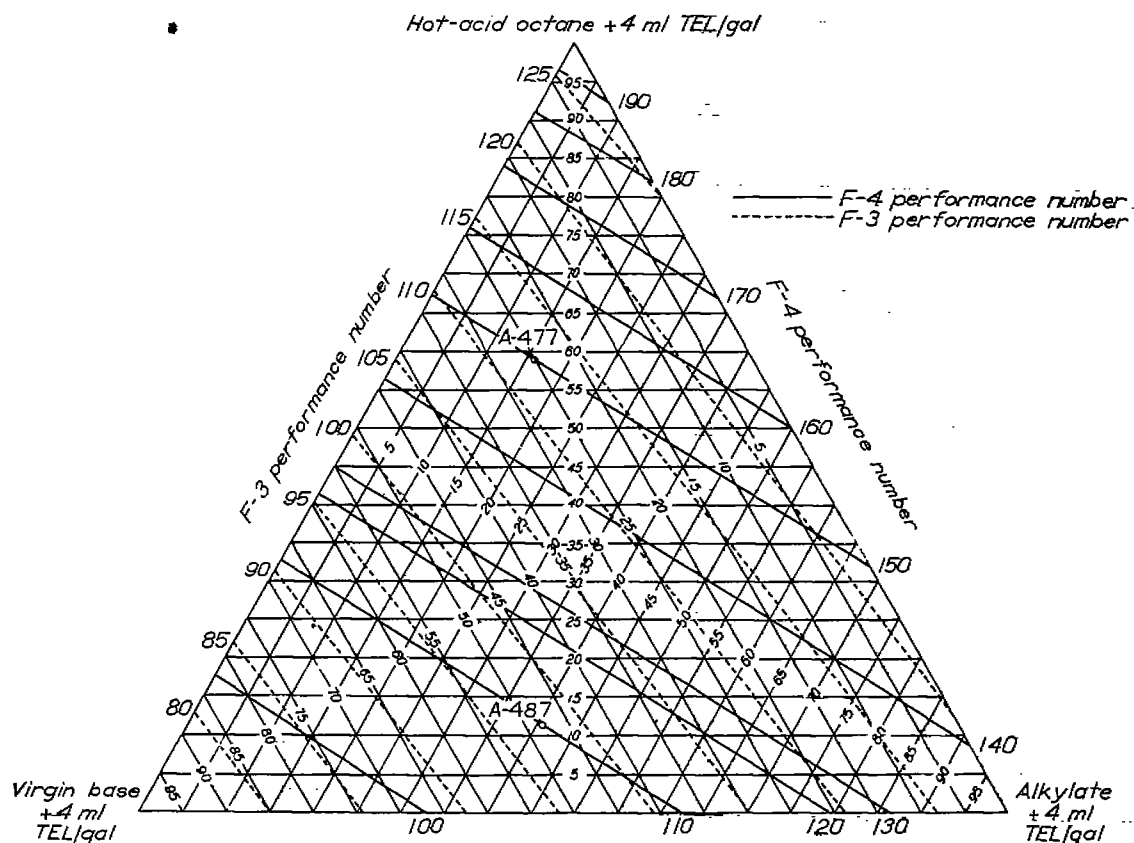
FIGURE 6.—Knock-limited performance determined by F-3 and F-4 rating methods for ternary blends containing hot-acid octane, aviation alkylate, and virgin base stock. F-4 ratings at fuel-air ratio of 0.11.

(a) Triptane blends; F-4 ratings at fuel-air ratio of 0.11.
(b) Diisopropyl blends; F-4 ratings at fuel-air ratio of 0.11.

FIGURE 7.—Knock-limited performance determined by F-3 and F-4 rating methods for ternary blends containing high-antiknock blending agents, aviation alkylate, and virgin base stock.

(c) Neohexane blends; F-4 ratings at fuel-air ratio of 0.11.
(d) Isopentane blends; F-4 ratings at fuel-air ratio of 0.11.

FIGURE 7.—Continued. Knock-limited performance determined by F-3 and F-4 rating methods for ternary blends containing high-antiknock blending agents, aviation alkylate, and virgin base stock.

(e) Benzene blends; F-4 ratings at fuel-air ratio of 0.11.

(f) Cumene blends; F-4 ratings at fuel-air ratio for peak power.

FIGURE 7.—Continued. Knock-limited performance determined by F-3 and F-4 rating methods for ternary blends containing high-antiknock blending agents, aviation alkylate, and virgin base stock.

(g) Mixed xylenes blends; F-4 ratings at fuel-air ratio of 0.11.
(h) Toluene blends; F-4 ratings at fuel-air ratio of 0.11.

FIGURE 7.—Continued. Knock-limited performance determined by F-8 and F-4 rating methods for ternary blends containing high-antiknock blending agents, aviation alkylate, and virgin base stock.

(l) Methyl tert-butyl ether blends; F-4 ratings at fuel-air ratio of 0.11.

FIGURE 7.—Concluded. Knock-limited performance determined by F-3 and F-4 rating methods for ternary blends containing high-antiknock blending agents, aviation alkylate, and virgin base stock.

(a) Hot-acid octane blends; F-4 ratings at fuel-air ratio of 0.11.

FIGURE 8.—Knock-limited performance determined by F-3 and F-4 rating methods for ternary blends containing high-antiknock blending agents, aviation alkylate, and one-pass catalytic stock.
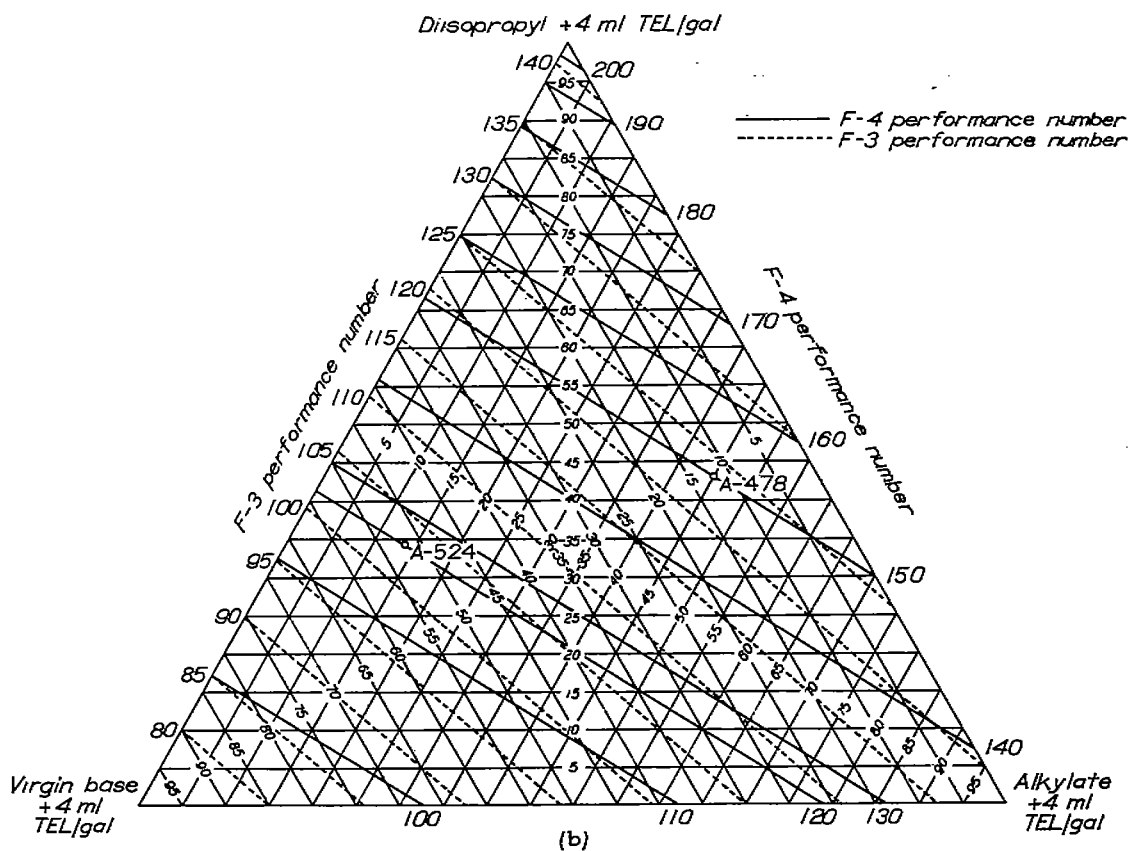
(b) Triptane blends; F-4 ratings at fuel-air ratio of 0.11.
(c) Diisopropyl blends; F-4 ratings at fuel-air ratio of 0.11.
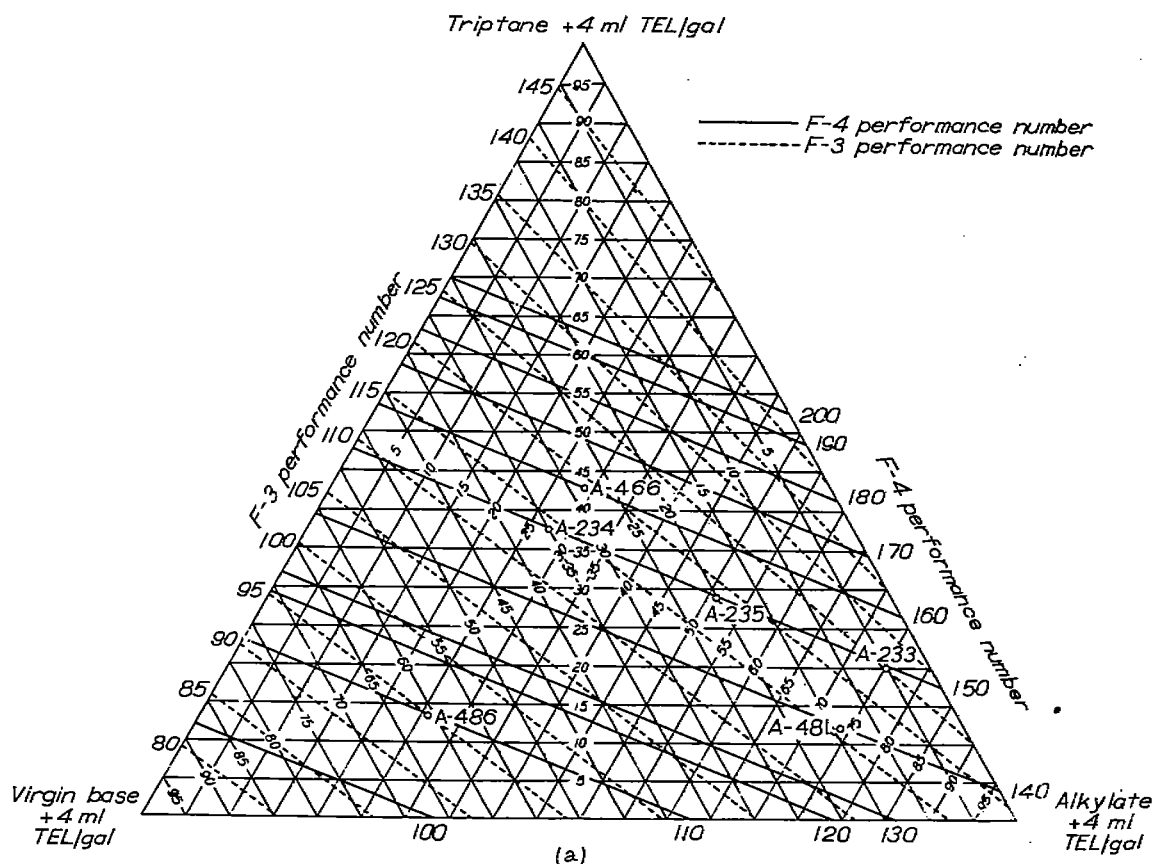
FIGURE 8.—Continued. Knock-limited performance determined by F-3 and F-4 rating methods for ternary blends containing high-antiknock blending agents, aviation alkylate, and one-pass catalytic stock.

(d) Neohexane blends; F-4 ratings at fuel-air ratio of 0.11.
(e) Isopentane blends; F-4 ratings at fuel-air ratio of 0.11.
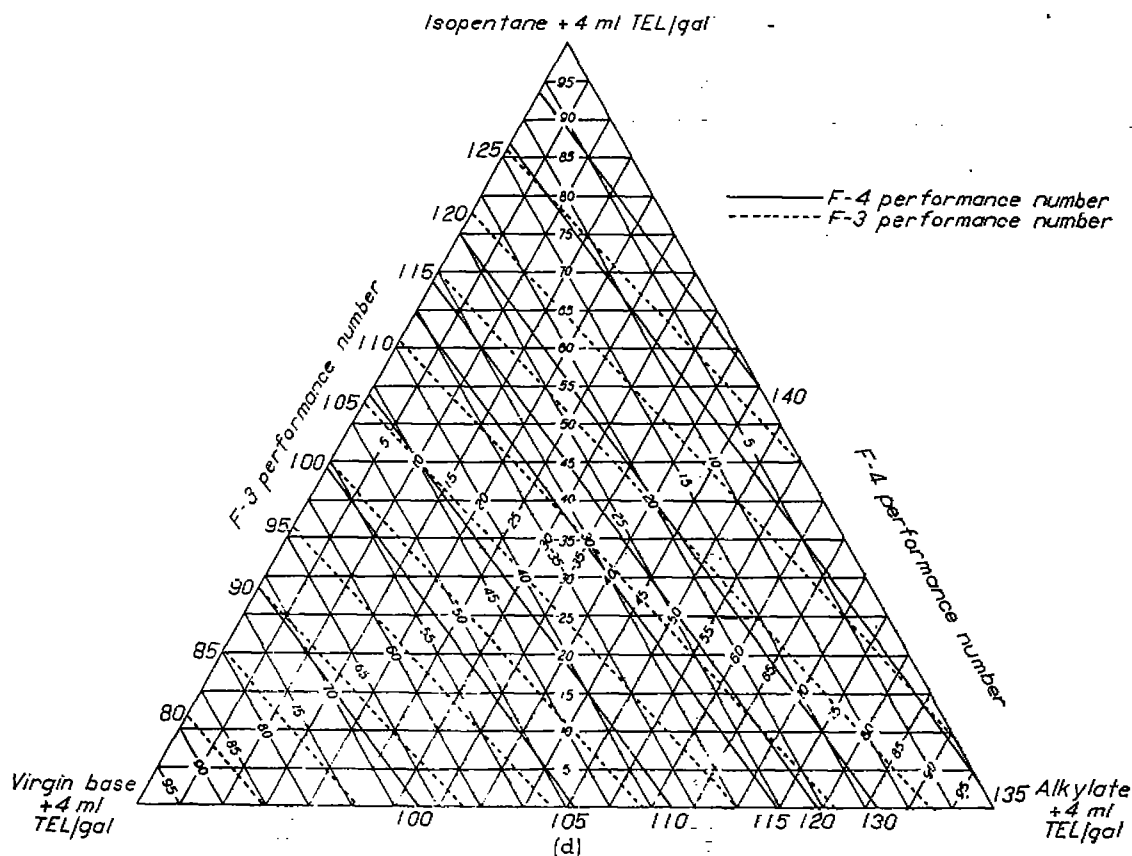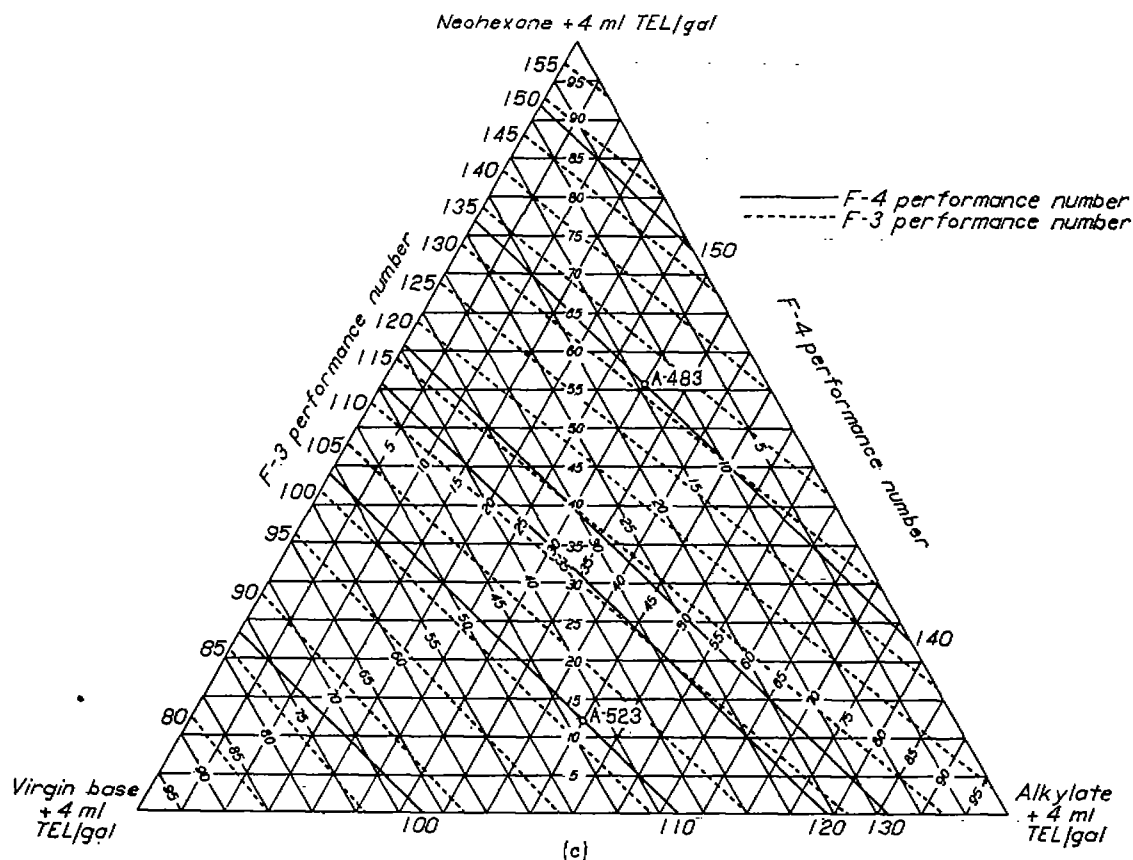
FIGURE 8.—Continued. Knock-limited performance determined by F-3 and F-4 rating methods for ternary blends containing high-antiknock blending agents, aviation alkylate, and one-pass catalytic stock.
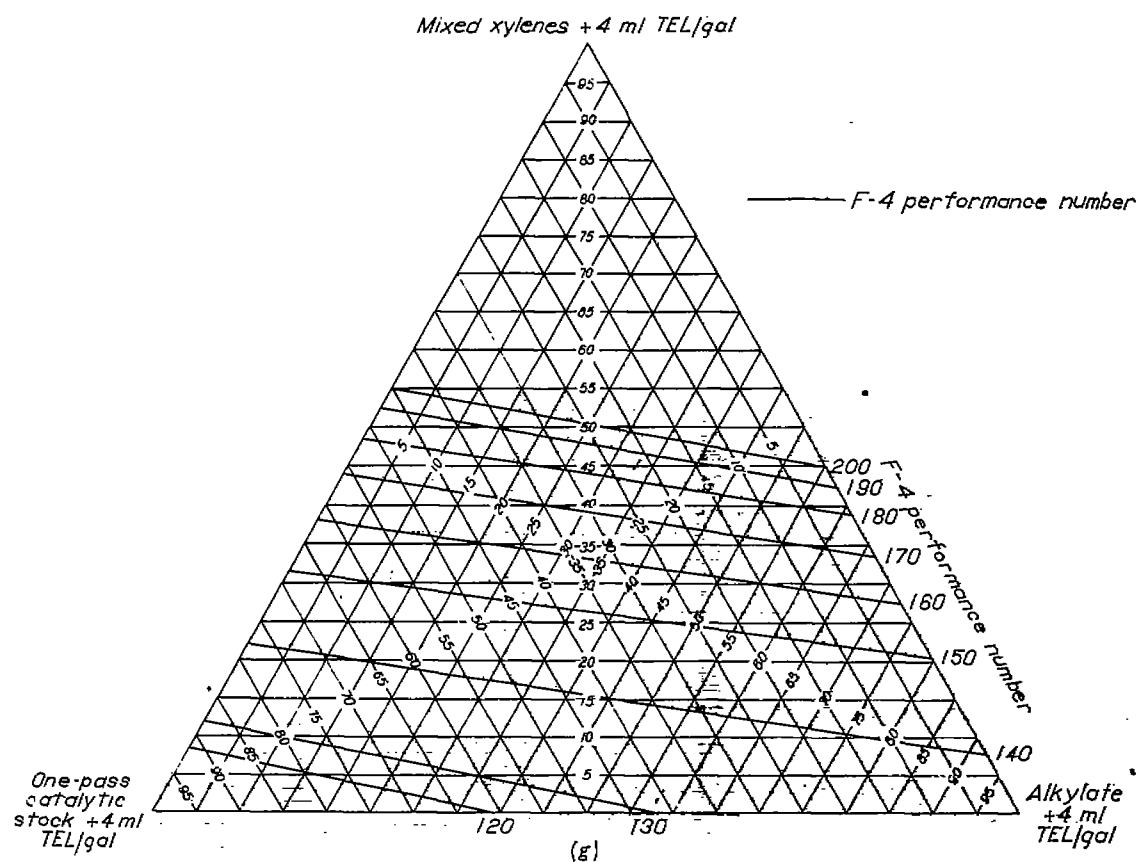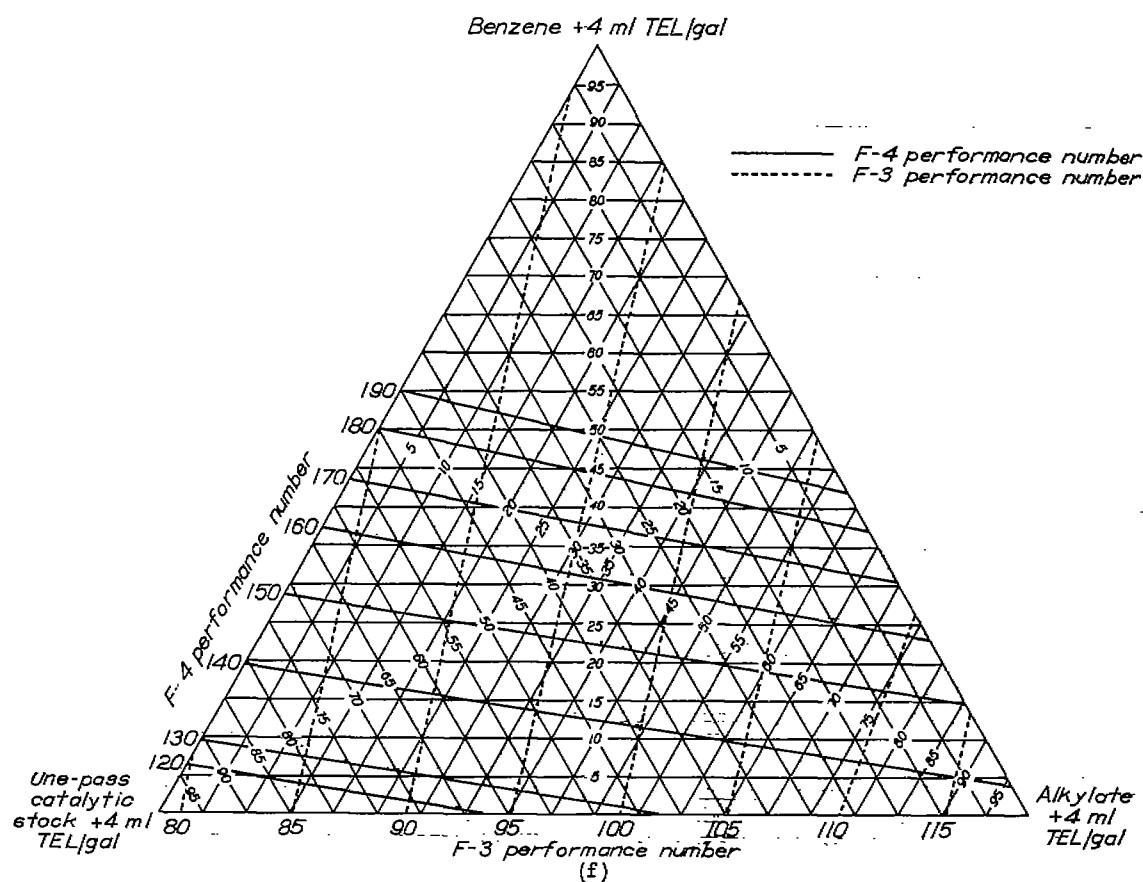
(f) Benzene blends; F–4 ratings at fuel-air ratio of 0.11.
(g) Mixed xylenes blends; F–4 ratings at fuel-air ratio of 0.11.

FIGURE 8.—Continued. Knock-limited performance determined by F–3 and F–4 rating methods for ternary blends containing high-antiknock blending agents, aviation alkylate, and one-pass catalytic stock.
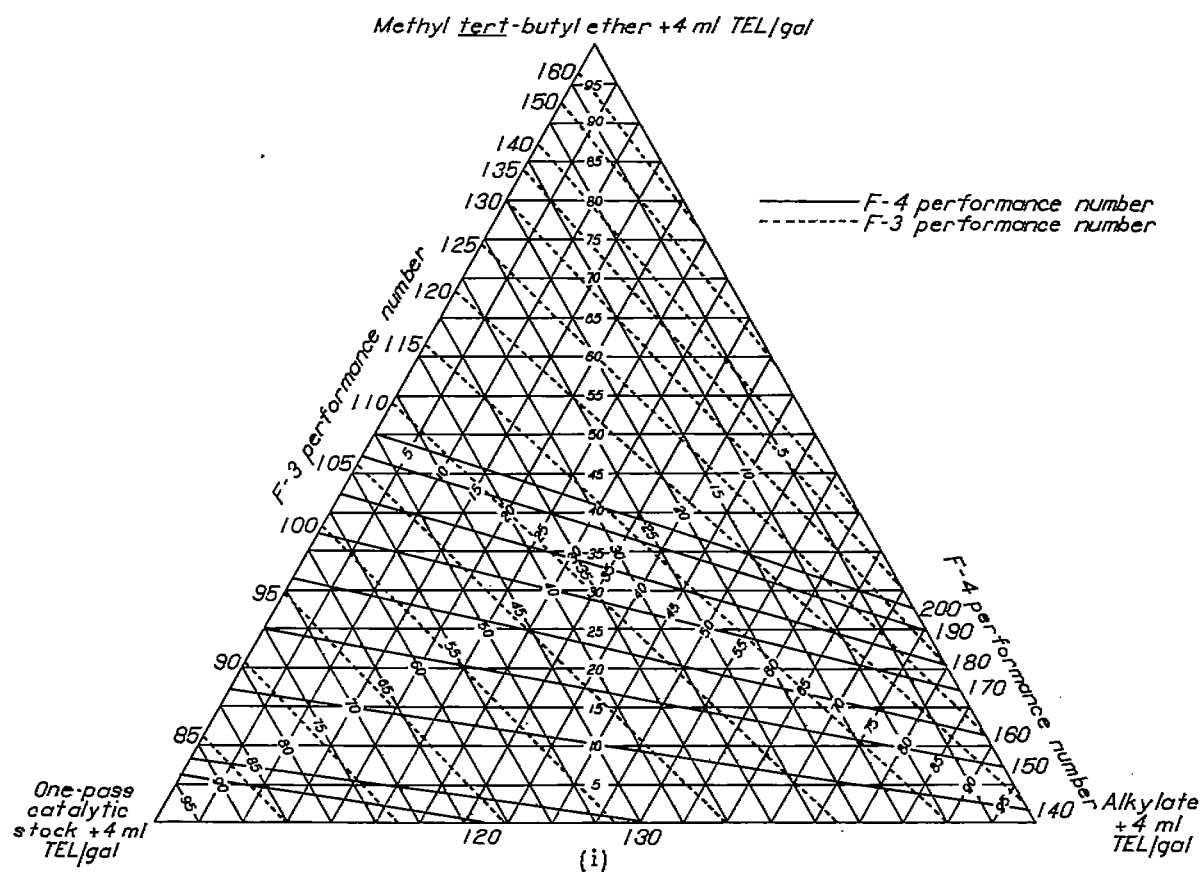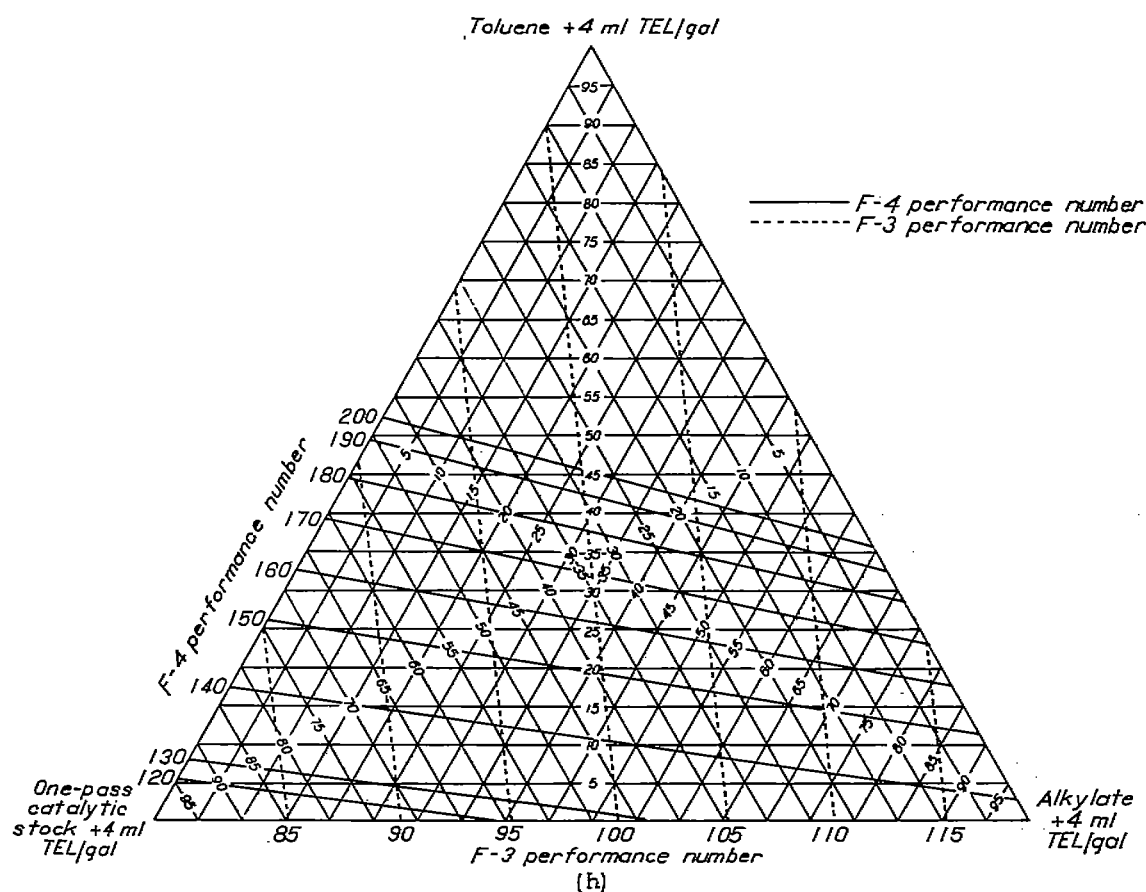
(h) Toluene blends; F-4 ratings at fuel-air ratio of 0.11.
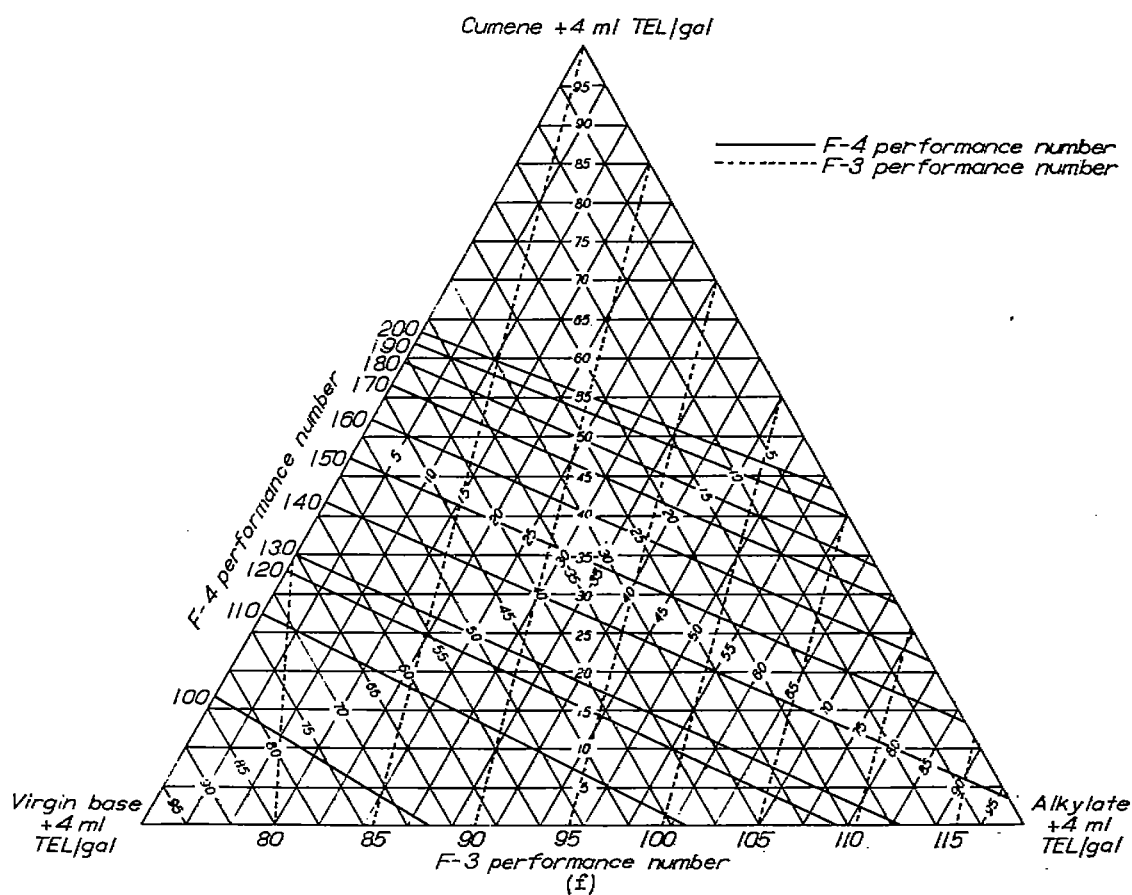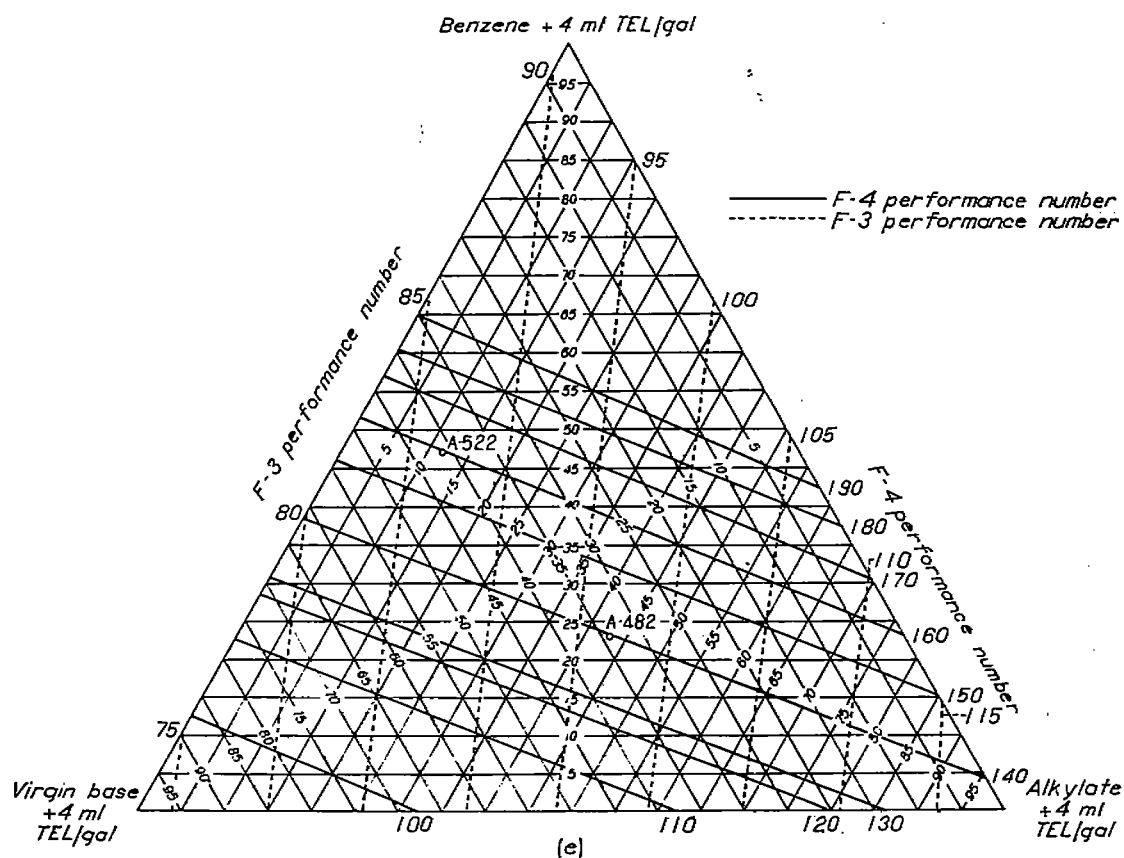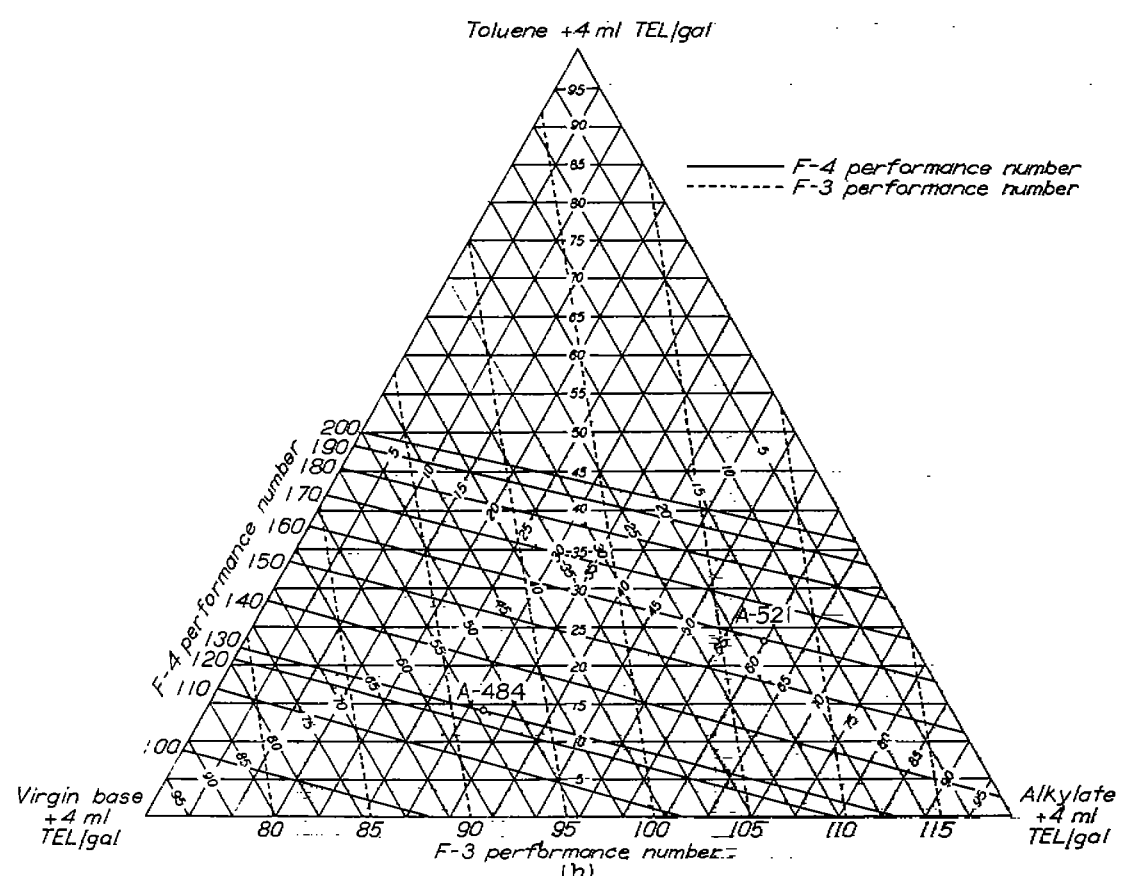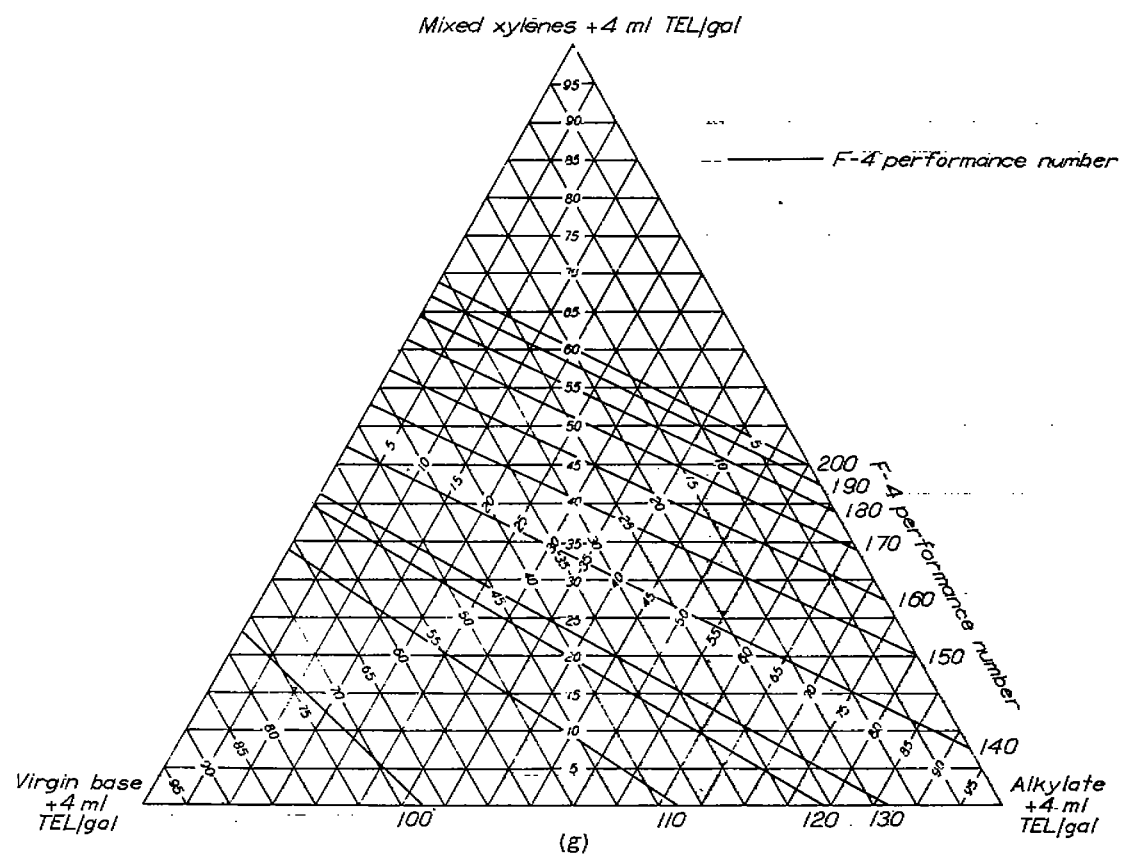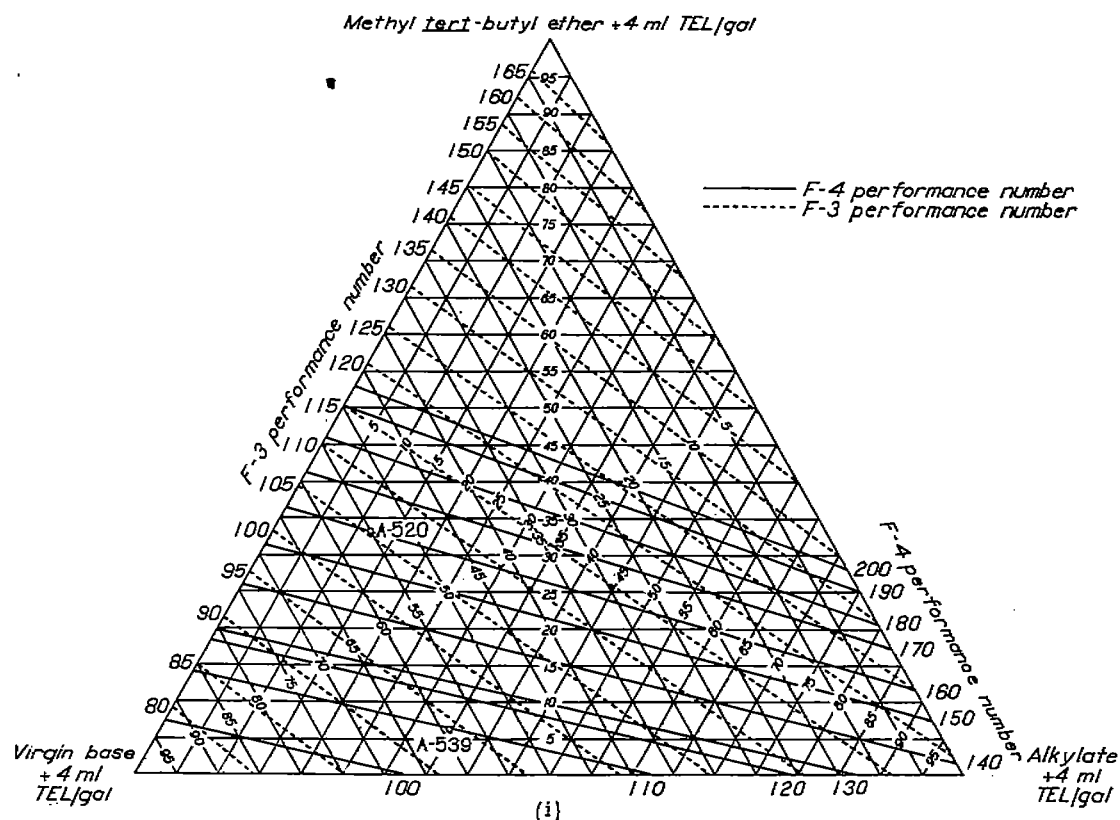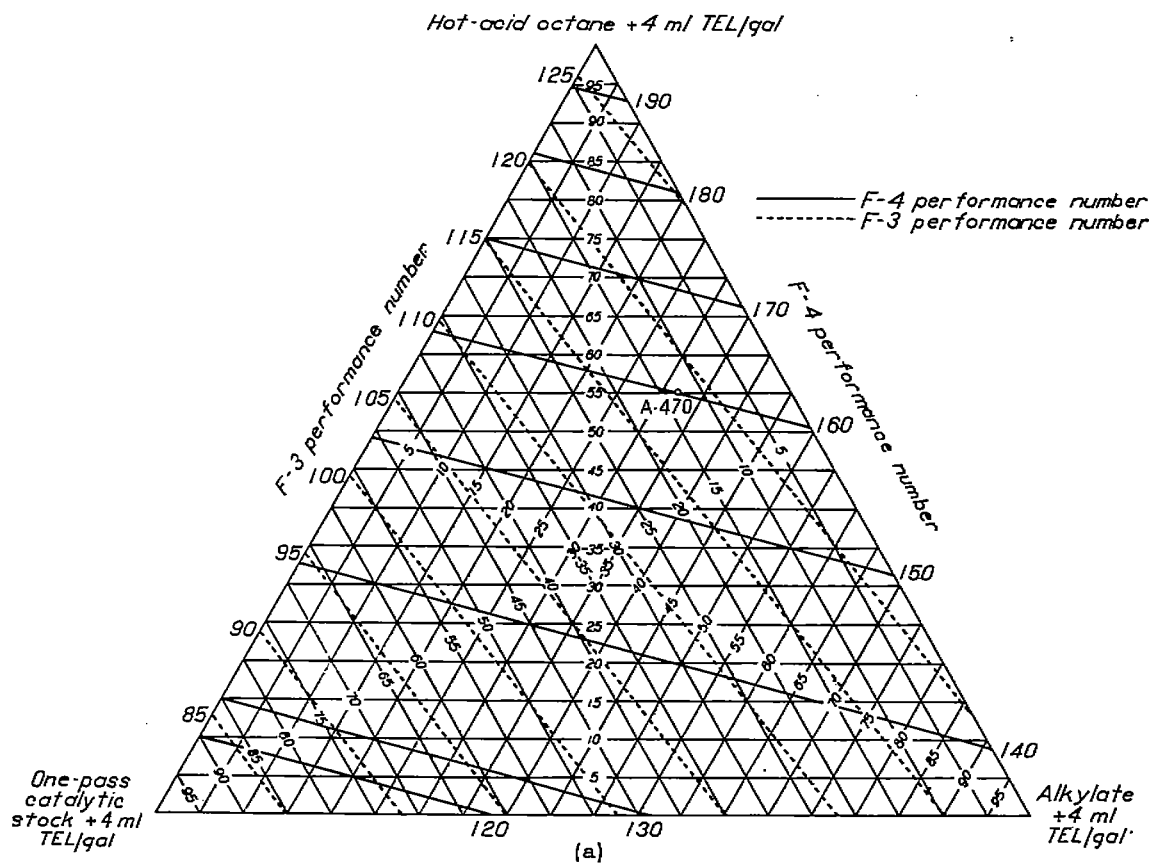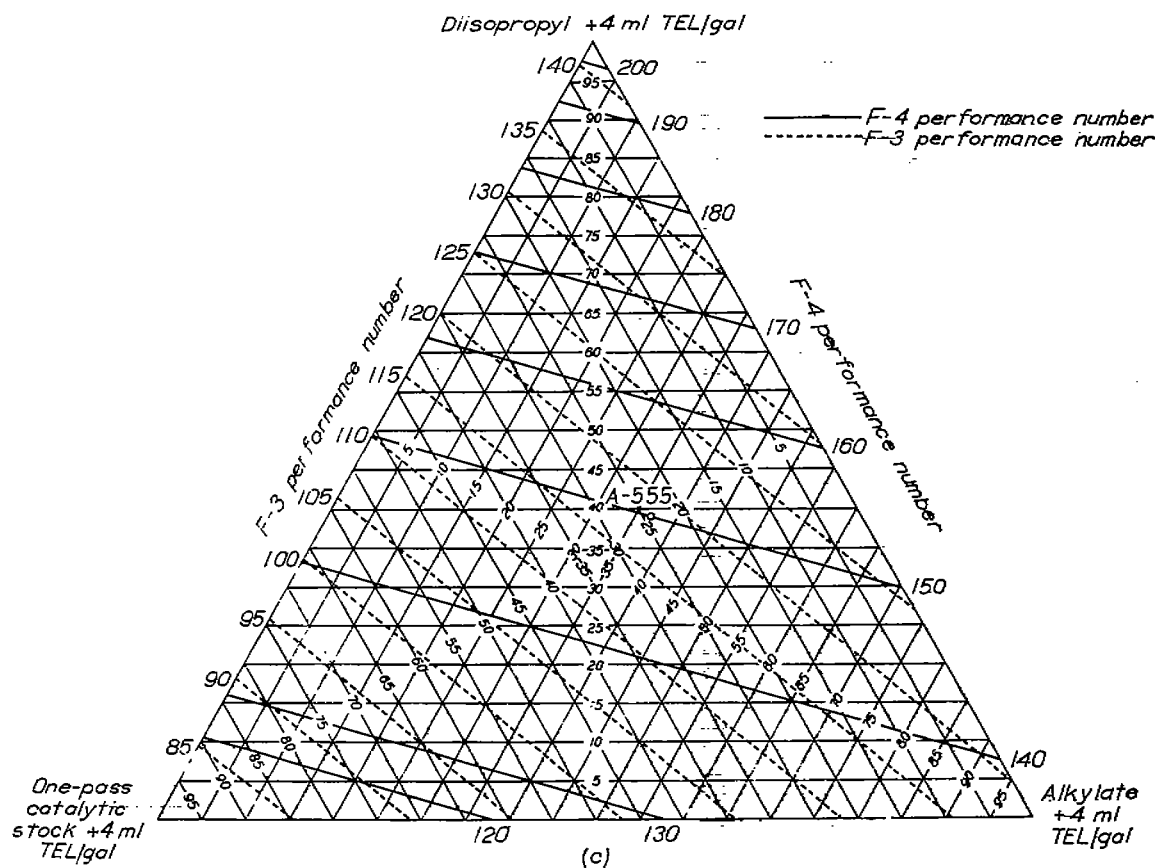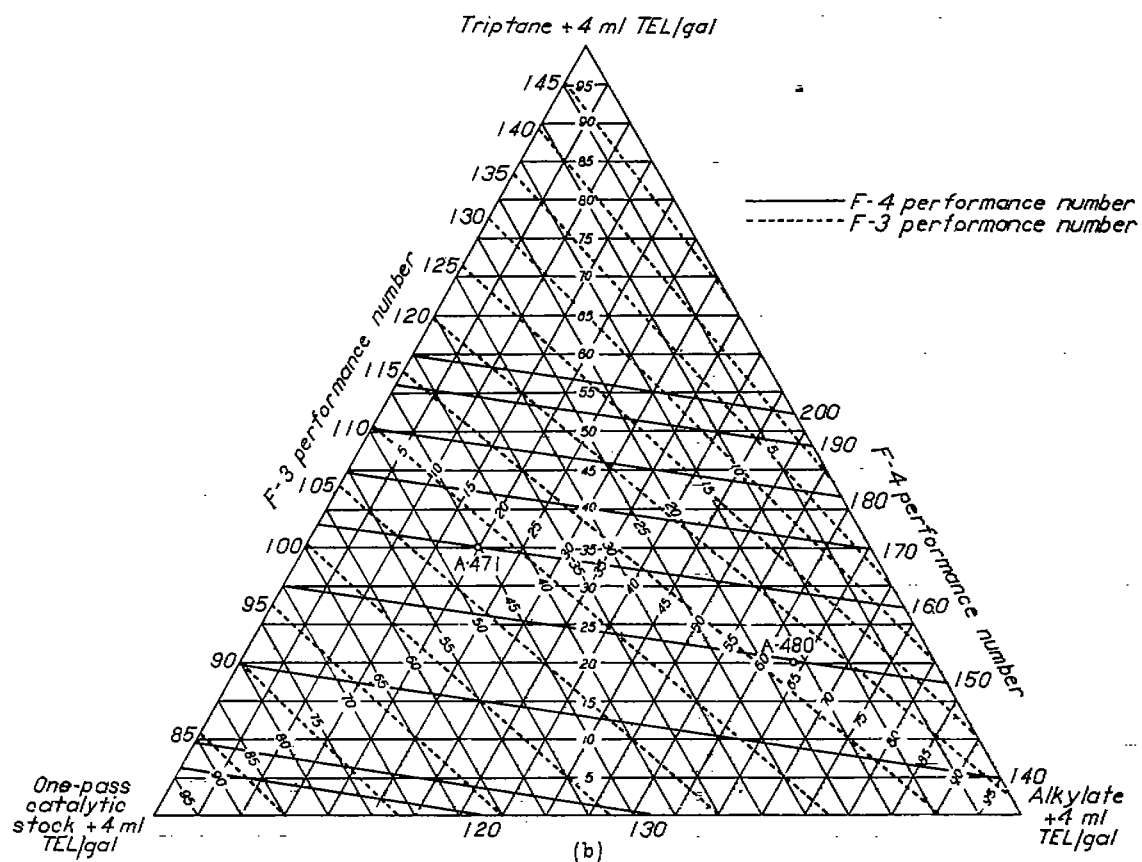(i) Methyl *tert*-butyl ether blends; F-4 ratings at fuel-air ratio of 0.11.

FIGURE 8.—Concluded. Knock-limited performance determined by F-3 and F-4 rating methods for ternary blends containing high-antiknock blending agents, aviation alkylate, and one-pass catalytic stock.

In figure 7 (f) the lines showing F–4 performance numbers for cumene blends were determined by plotting peak knock-limited power values rather than power values at a fuel-air ratio of 0.11. This deviation from the procedure used for all other plots in figures 6, 7, and 8 was necessary because most of the mixture-response curves for the cumene blends investigated (reference 1) intersected at fuel-air ratios between 0.10 and 0.11. (See fig. 9.) The fuel-air ratio for peak knock-limited power varied between 0.115 and 0.132 for the cumene blends used in preparing figure 7 (f).

No plot was prepared for blends of cumene, aviation alkylate, and one-pass catalytic stock because rich-mixture peaks were not obtained for a sufficient number of the binary blends of cumene and one-pass catalytic stock reported in reference 1.

Lines of F–3 performance for xylenes blends were not plotted in figures 7 (g) and 8 (g) because the curve of composition against F–3 ratings for binary blends of xylenes and aviation alkylate passed through a minimum. (See fig. 10.)

In general, data obtained on the F–3 engine for the aromatic blends could not be handled with complete satisfaction by the empirical procedure previously explained. For this reason, the accuracy of the lines of constant F–3 performance shown for the aromatic-paraffinic systems in figures 7 and 8 is questionable.

QUATERNARY BLENDS

The performance charts presented in figures 6, 7, and 8 are of interest primarily from considerations of maxmium knock-limited performance attainable with various combinations of fuel blending agents and current base stocks. The producers of aviation fuel, however, are interested in the maximum knock-free power attainable with a finished blend that meets physical-property specifications for aviation fuels. In the present analysis, an attempt has been made to show how performance charts can be prepared for ternary blends in which each of the components has been isopentanized to a Reid vapor pressure of 7 pounds per square inch.
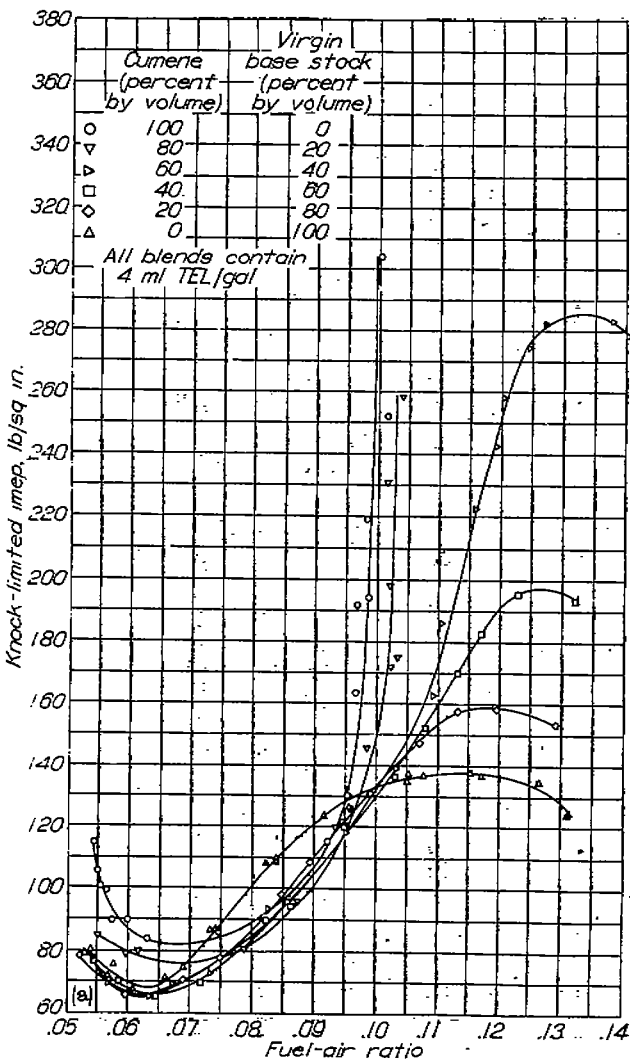
(a) Blends with virgin base stock.
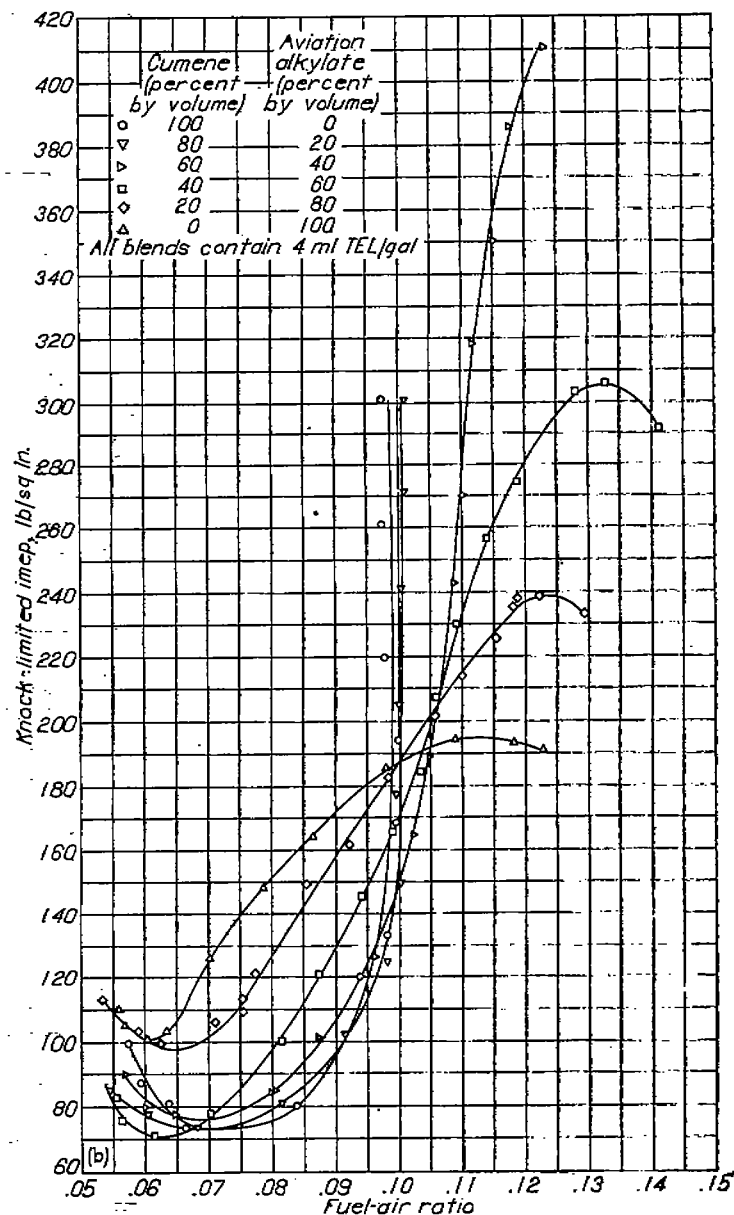
(b) Blends with aviation alkylate.

FIGURE 9.—Knock-limited performance of binary blends of cumene with aviation alkylate, virgin base stock, and one-pass catalytic stock as determined in F-4 rating engine.
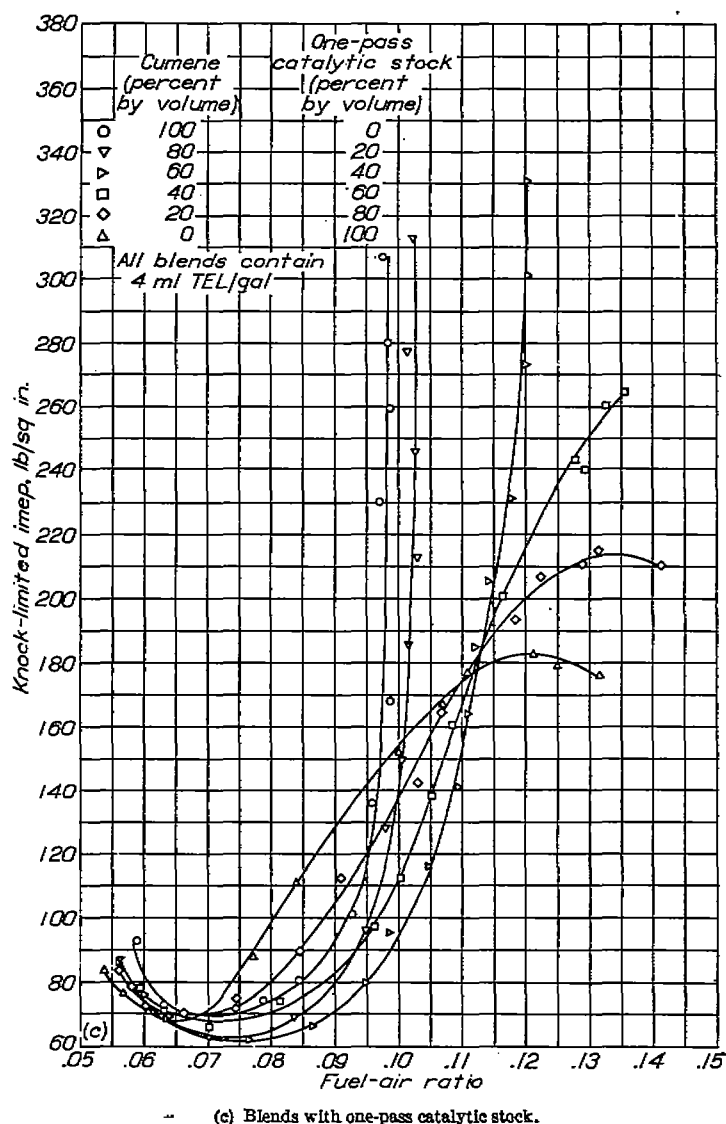
(c) Blends with one-pass catalytic stock.

FIGURE 9.—Concluded. Knock-limited performance of binary blends of cumene with aviation alkylate, virgin base stock, and one-pass catalytic stock as determined in F-4 rating engine.
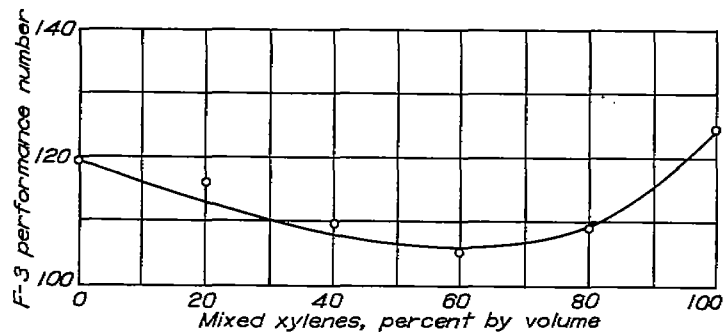
FIGURE 10.—Knock-limited performance determined by F-3 rating method for binary blends of mixed xylenes with aviation alkylate.

The addition of isopentane to adjust the vapor pressure of the components in a system such as that shown in figure 7 (a) will necessarily affect the maximum knock-free power attainable because of the performance rating of isopentane relative to the ratings of the other components in the system. (See table II.) In figure 7 (a), for example, a blend of 58.5-percent triptane, 30.5-percent alkylate, and 11-percent virgin base stock has a lean-rich performance-number rating of

135/200 and a Reid vapor pressure of approximately 3.5 pounds per square inch (estimated from table II). In order to obtain the same performance (135/200) with a blend of triptane, alkylate, and virgin base stock that has been isopentanized to a Reid vapor pressure of 7 pounds per square inch (maximum from specification), a blend of 55-percent triptane, 17-percent alkylate, 7-percent virgin base stock, and 21-percent isopentane could be used. The addition of isopentane has thus effectively decreased the quantity of triptane needed to obtain the 135/200 performance rating, which is attributed to the fact that isopentane has better performance characteristics than the alkylate or the virgin base stock used as well as a higher Reid vapor pressure than the other three constituents in the blend. (See table II.)

It must be emphasized that the preceding example is merely given as a sample consideration of a fuel characteristic other than knock that must be considered for a finished fuel blend. This example is not intended to imply that the preparation of fuel blends as presented herein with Reid vapor pressures adjusted to meet specifications will necessarily produce blends that will meet all pertinent specifications.

Several performance charts for quaternary blends containing isopentane were prepared for comparison with the charts previously described for ternary blends. In each of the quaternary systems, the vapor pressure was adjusted to 7 pounds per square inch. Three assumptions were made in the preparation of these charts:

(1) The relation between composition (volume basis) and Reid vapor pressure for binary blends of isopentane with another paraffinic fuel is linear.

(2) The relation between composition and the reciprocal of F-4 (rich) knock-limited indicated mean effective pressure for binary blends of isopentane with another paraffinic fuel is linear.

(3) The relation between composition and F-3 performance number for binary blends of isopentane with another paraffinic fuel is linear.

On the basis of the available data, assumption (3) appears to be valid for only a few cases. For this reason the F-3 performance lines on the charts for quaternary blends may be in error.

As an example of the preparation of the performance chart for a quaternary system, it is assumed desirable to isopentanize the blends represented by figure 7 (a). The first step in this problem is to determine the amount of isopentane to be added to each of the pure components (fig. 7 (a)) to obtain a Reid vapor pressure of 7 pounds per square inch and to determine the resultant F-3 and F-4 performance-number ratings for these blends. This information was obtained from the foregoing assumptions and the data in table II and is presented in the following table:

	F-3 performance number	F-4 indicated mean effective pressure (lb/sq in.)
76% triptane+24% isopentane+4 ml TEL/gal	145	455
85% alkylate+15% isopentane+4 ml TEL/gal	121	200
92% virgin base+8% isopentane+4 ml TEL/gal	78	142
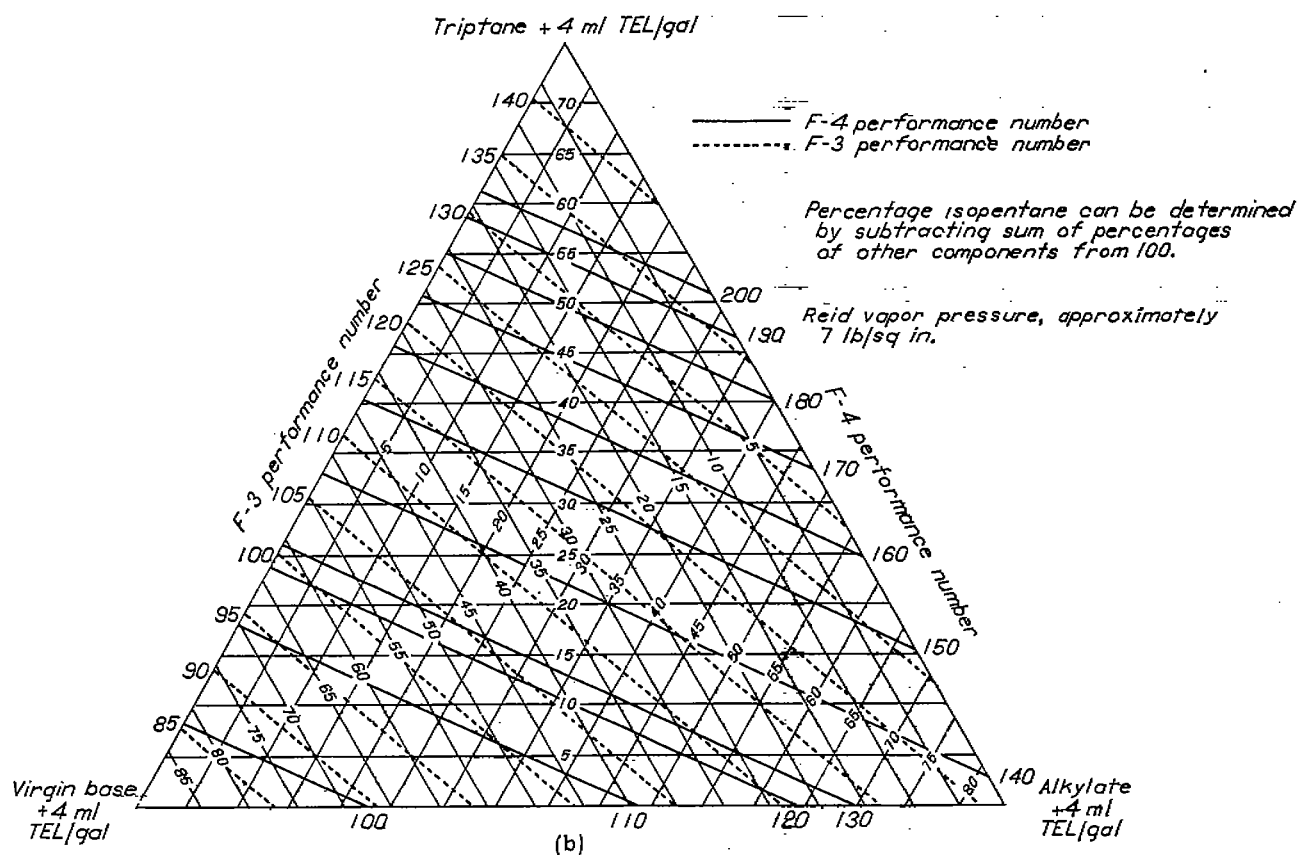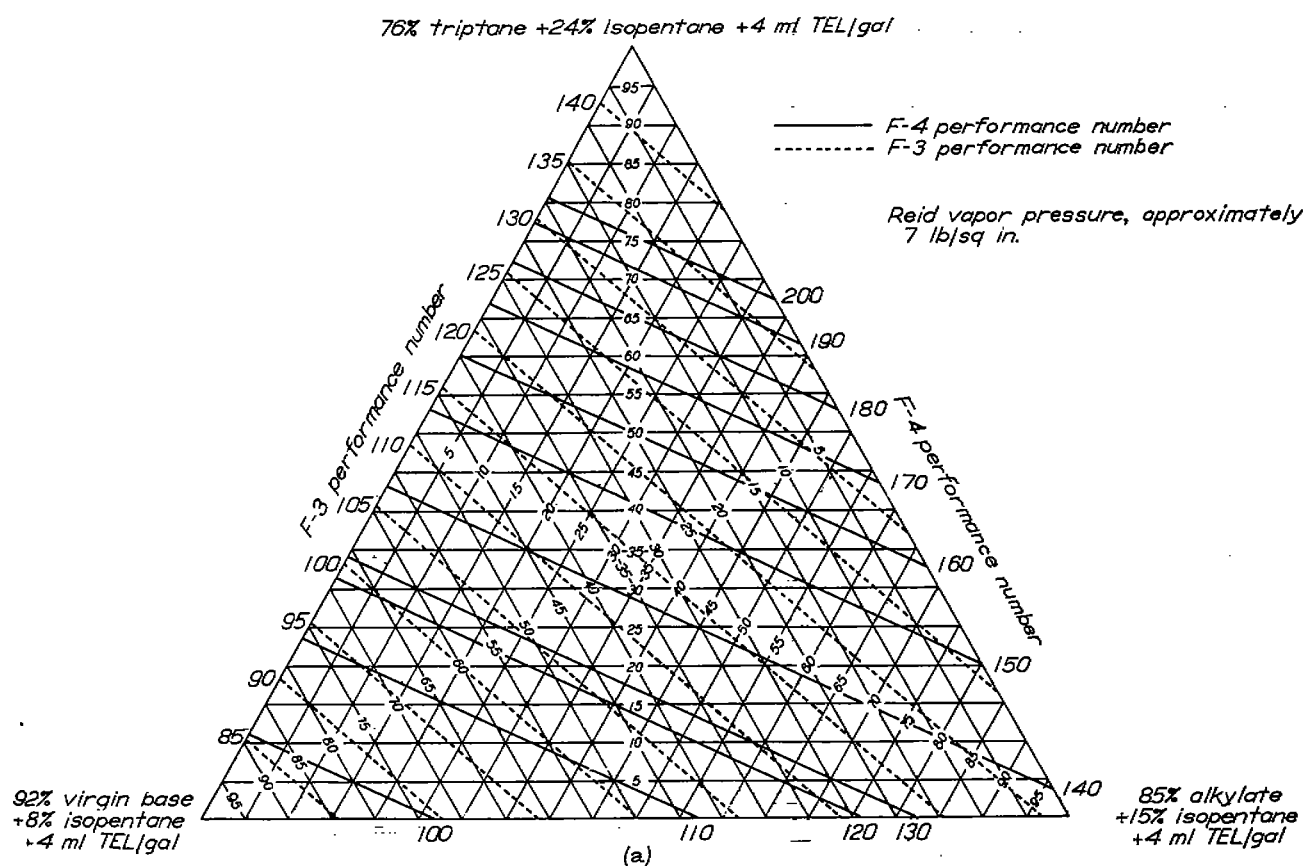
(a) Plain triangular coordinate.

(b) Triangular coordinate adjusted to show blend composition in terms of concentrations of individual constituents.
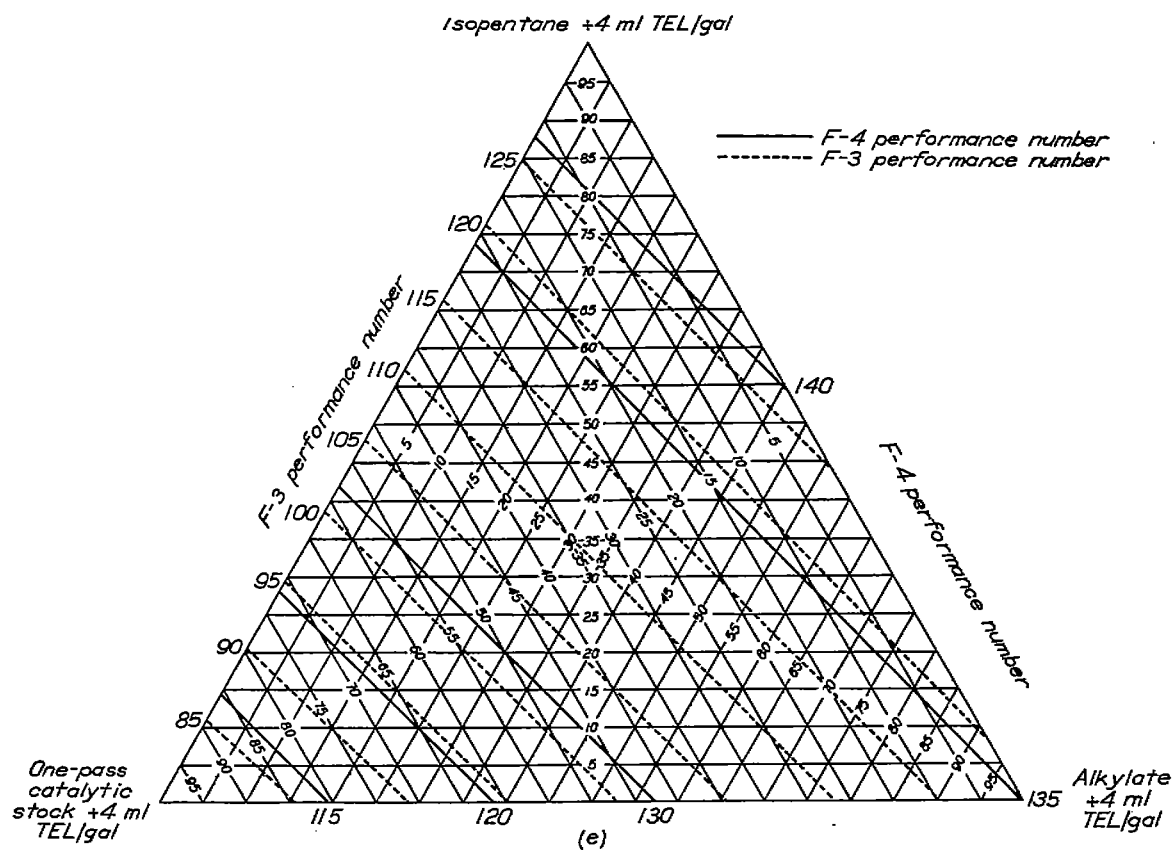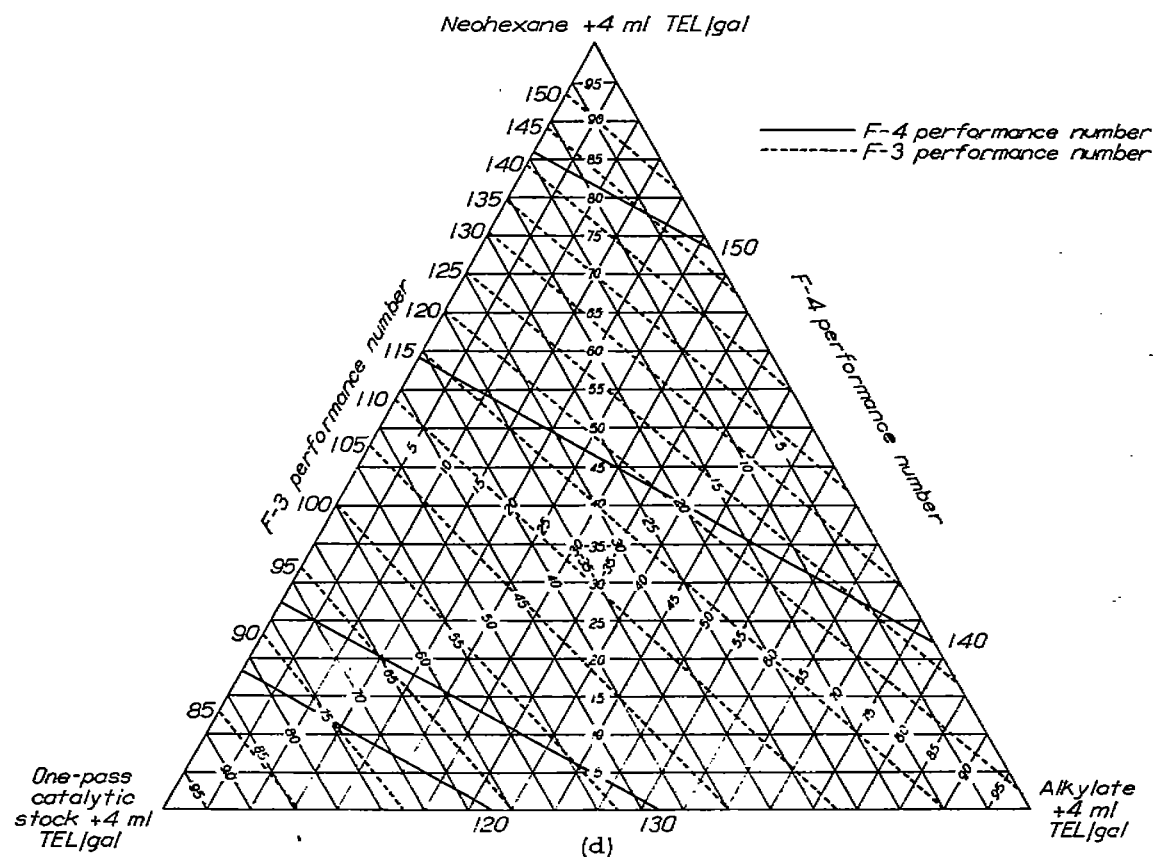
FIGURE 11.—Knock-limited performance determined by F-3 and F-4 rating methods for quaternary blends containing triptane, aviation alkylate, virgin base stock, and isopentane. F-4 ratings at fuel-air ratio of 0.11.

The triangular chart shown in figure 11 (a) was obtained by treating these three blends (all of which have Reid vapor pressures of 7 lb/sq in.) as separate components by the procedure used in preparing figure 7 (a). Any point on figure 11 (a) represents the F-3 and F-4 performance number of a quaternary blend. The actual quantity of each component in the blend, however, cannot be readily determined from the chart because the percentages given on the altitudes of the triangle show only the amounts of the binary blends at the vertexes. For this reason, the grid of the chart was so adjusted, as shown in figure 11 (b), that the quantity of any one of the four components in the blend could be determined from the chart.

As an example of the method of determining the composition of fuel in figure 11 (b), it is assumed that a blend of triptane, aviation alkylate, virgin base stock, and isopentane having a lean-rich rating of 130/180 is desired. The concentrations of triptane, alkylate, and virgin base stock in the blend having the desired rating can be read directly from the altitudes of the triangle in the manner used in previous charts. These concentrations are 48, 19, and 13 percent, respectively. The concentration of isopentane can be determined by subtracting the sum of the percentages of the other components from 100.

Performance charts for the following quaternary systems have been prepared and are presented in figure 12:

Triptane, hot-acid octane, aviation alkylate, and isopentane

Triptane, diisopropyl, aviation alkylate, and isopentane
Triptane, diisopropyl, hot-acid octane, and isopentane
Diisopropyl, hot-acid octane, aviation alkylate, and isopentane

The vapor pressure determined for the diisopropyl used in figure 12 was 7.4 pounds per square inch. (See table II.) In the preparation of figure 12, however, a vapor pressure of 7 pounds per square inch was assumed for diisopropyl.

ACCURACY OF PERFORMANCE CHARTS

The accuracy of the charts was determined by selecting ternary or quaternary blends from the various charts and investigating these blends by the standard F-3 and F-4 procedures. Inasmuch as the F-4 ratings shown on the charts were estimated at a fuel-air ratio of 0.11, the check ratings were determined at this same fuel-air ratio.

The check blends investigated and their ratings are shown in table III. These blends are also shown on the various charts by the symbols. The fuel numbers shown adjacent to each of the symbols on the charts correspond to the fuel numbers given in this table. All the data in table III are presented in figure 13 to show the relation between estimated and observed performance numbers. For the 25 blends shown in figure 13, the average deviation from the match line was 3.1 performance numbers for the F-3 ratings and 1.5 for the F-4 ratings.
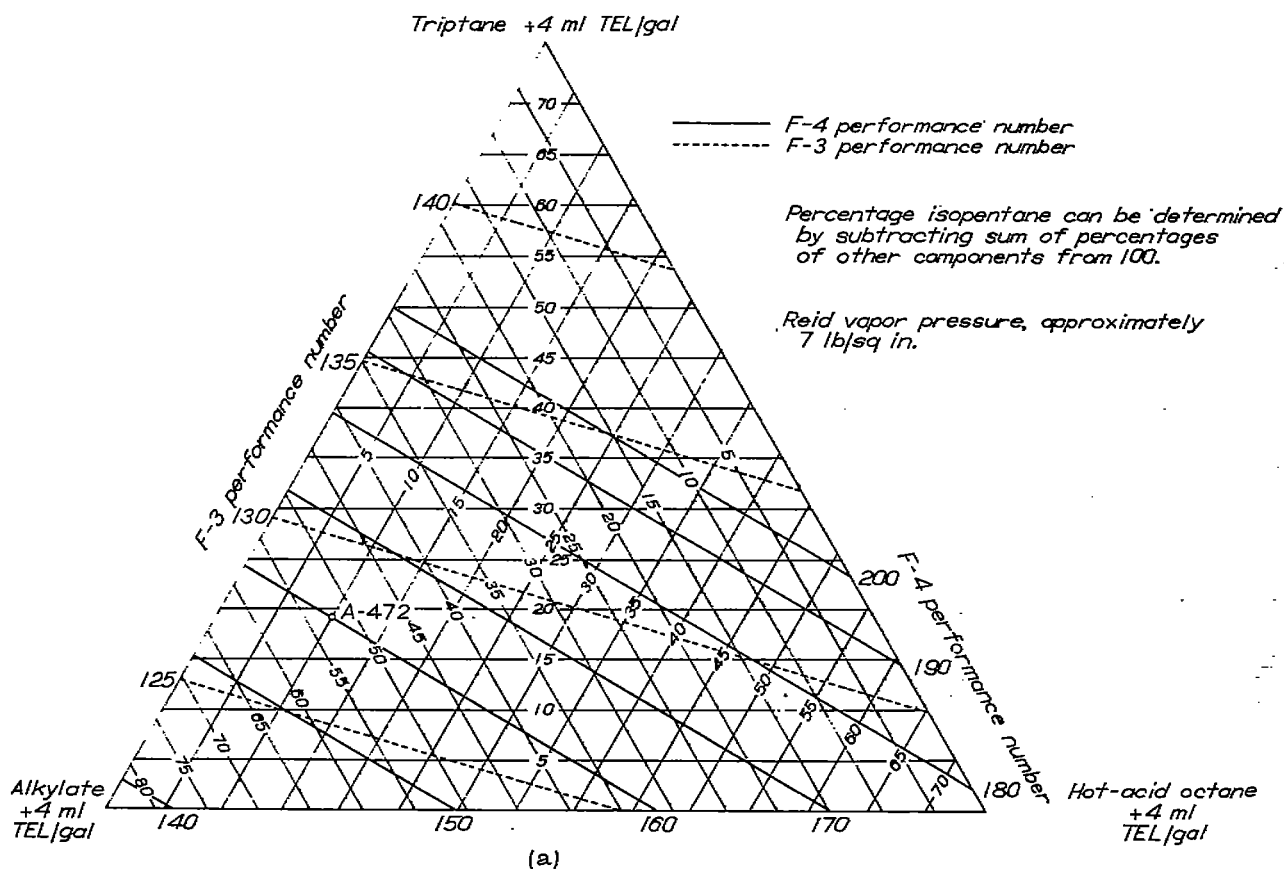
(a) Blends of triptane, hot-acid octane, aviation alkylate, and isopentane; F-4 ratings at fuel-air ratio of 0.11.

FIGURE 12.—Knock-limited performance determined by F-3 and F-4 rating methods for quaternary blends.
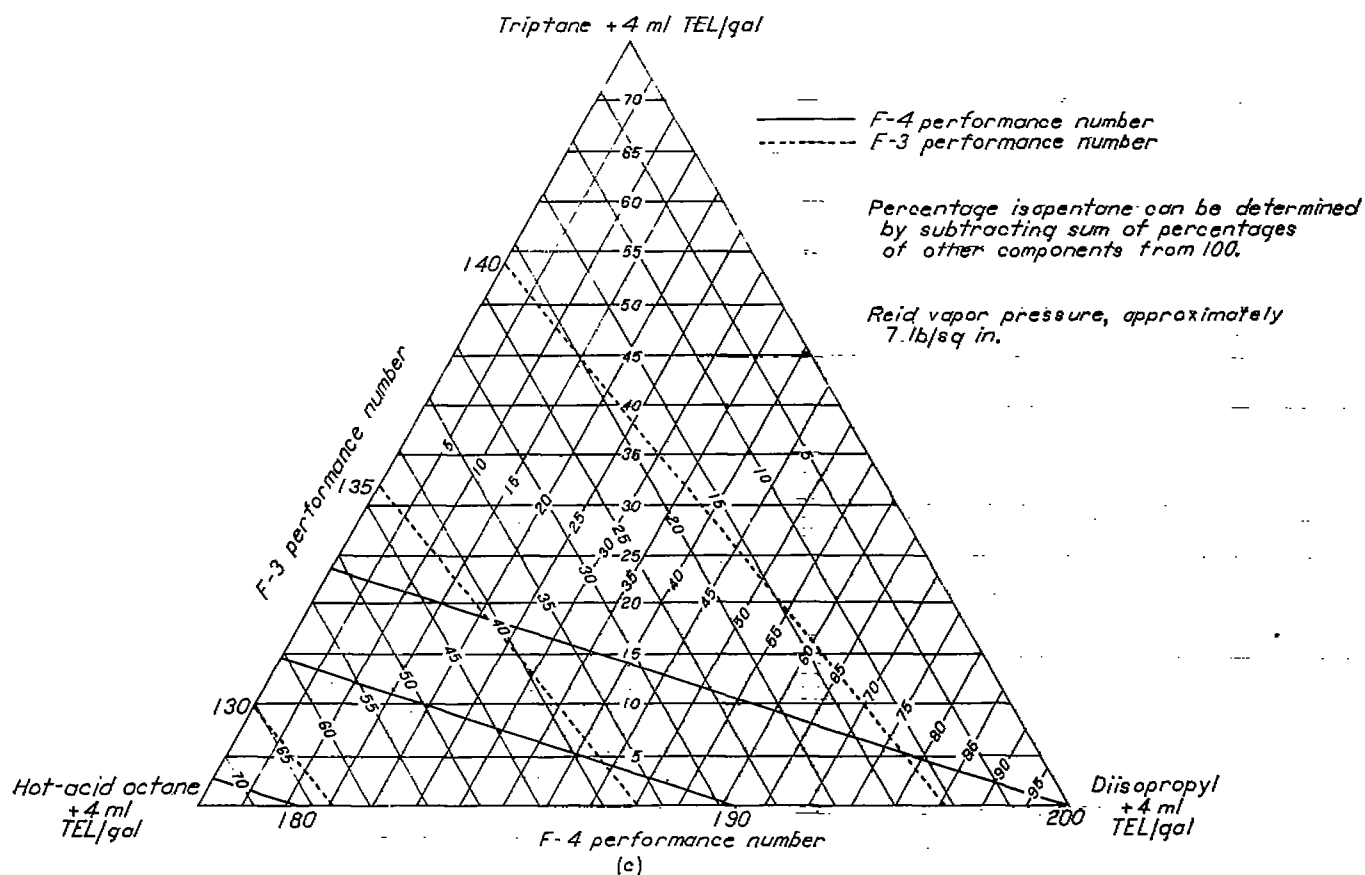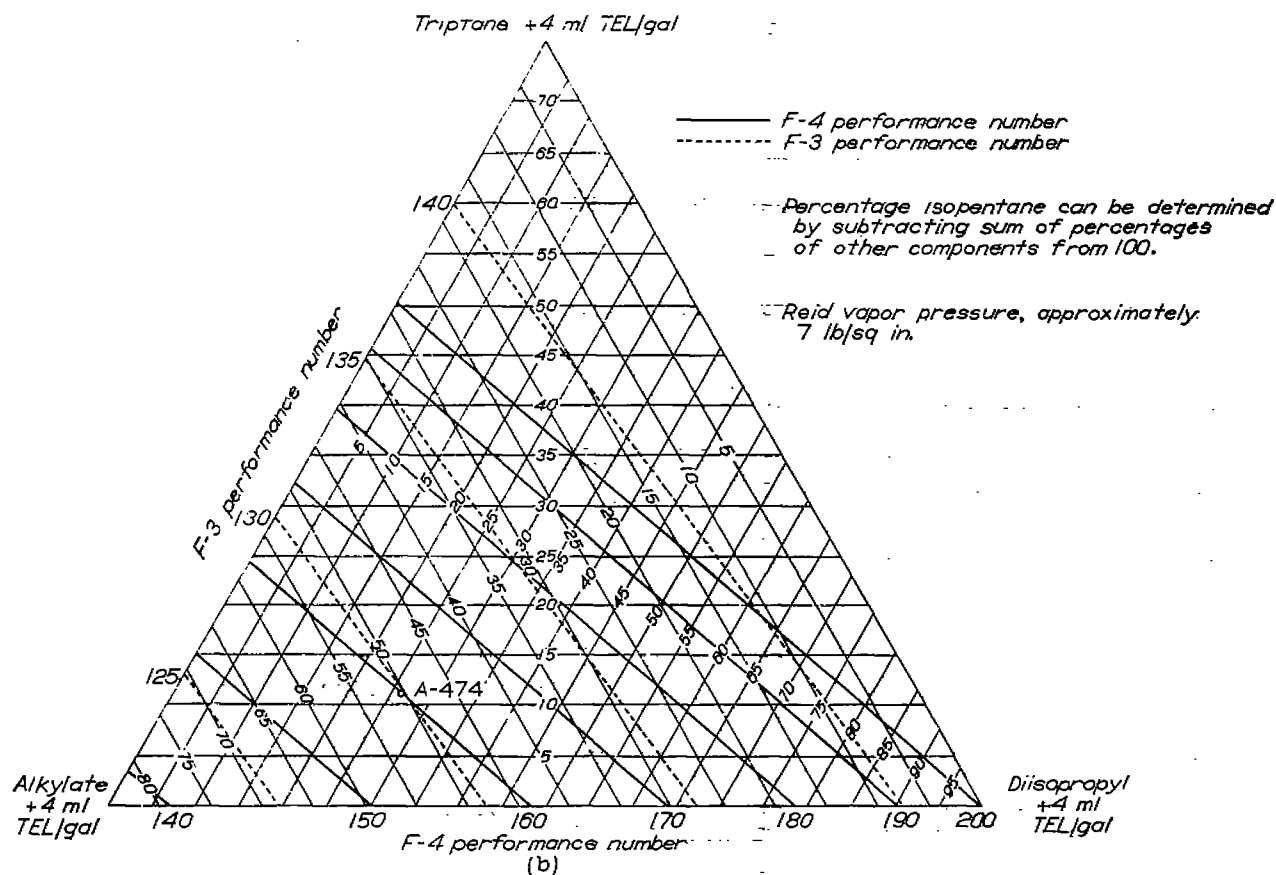
(b) Blends of triptane, diisopropyl, aviation alkylate, and isopentane; F-4 ratings at fuel-air ratio of 0.11.
(c) Blends of triptane, diisopropyl, hot-acid octane, and isopentane; F-4 ratings at fuel-air ratio of 0.11.

FIGURE 12.—Continued. Knock-limited performance determined by F-3 and F-4 rating methods for quaternary blends.
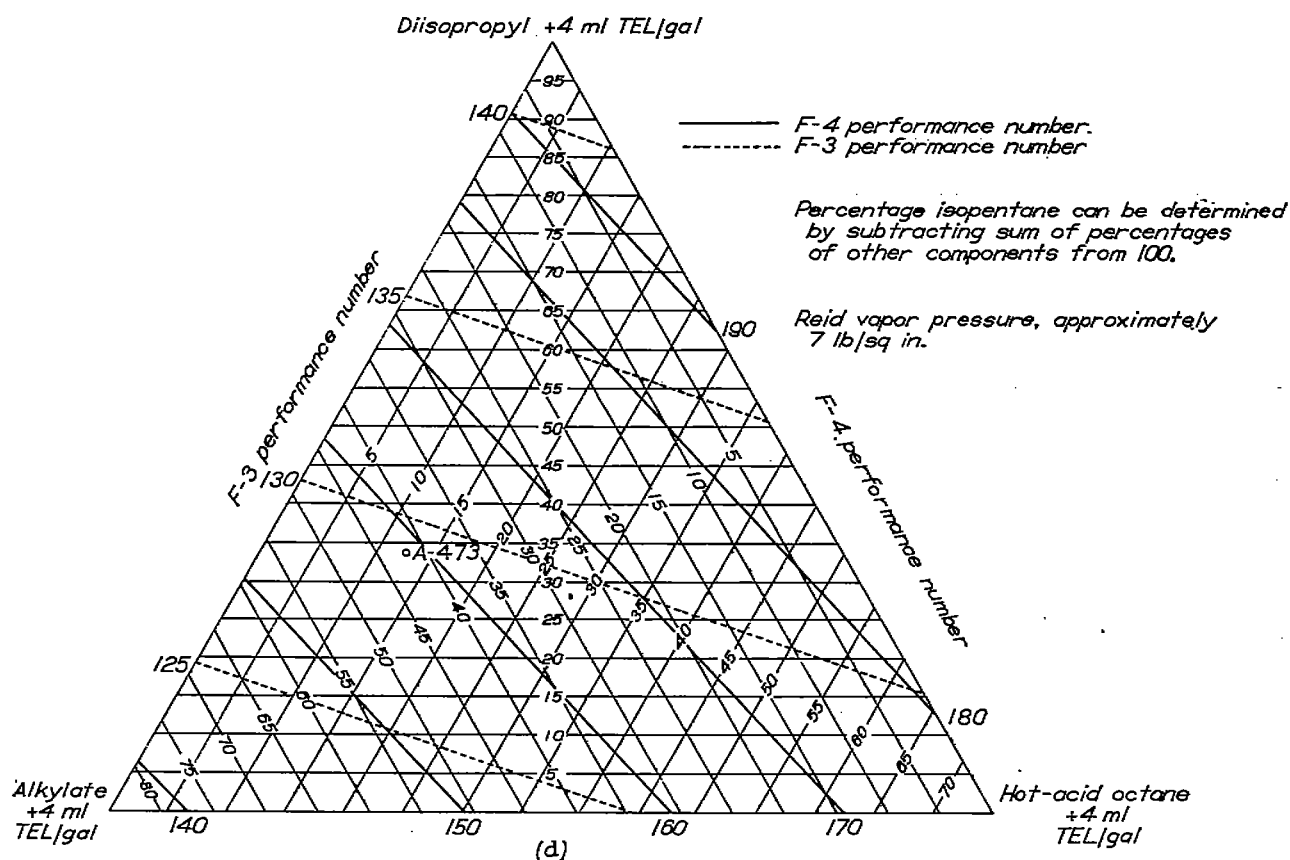
(d) Blends of diisopropyl, hot-acid octane, aviation alkylate, and isopentane; F-4 ratings at fuel-air ratio of 0.11.

FIGURE 12.—Concluded. Knock-limited performance determined by F-3 and F-4 rating methods for quaternary blends.
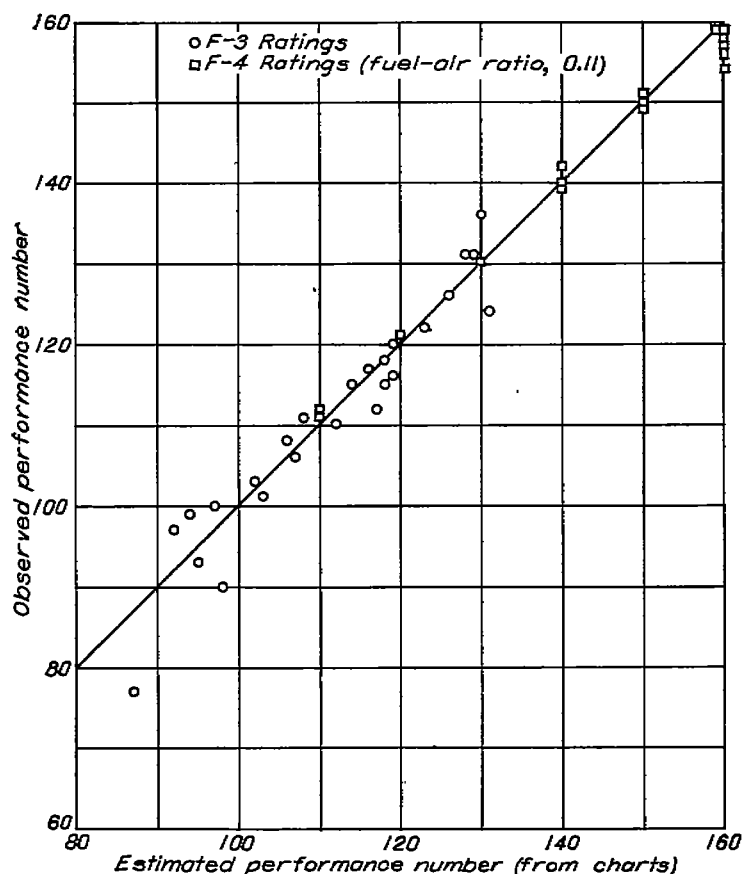
FIGURE 13.—Relation between estimated and observed knock-limited performance ratings as determined by F-3 and F-4 rating methods.

In consideration of the accuracy of the charts it must be emphasized that the previously mentioned discrepancies noted in the F-3 ratings of binary blends containing aromatics are responsible for some of the large deviations in table III. For this reason the F-3 performance lines for the aromatic systems shown in figures 7 and 8 must be used with considerable caution.

DISCUSSION OF PERFORMANCE CHARTS

The data in figures 7 and 8 can be used for certain general comparisons of paraffins, aromatics, and ethers. In figure 7 (a), for example, at the point representing a blend of 81-percent aviation alkylate, 19-percent virgin base stock, and 4 ml TEL per gallon, the lean-rich rating is 110/123. Moving on a straight line from this point toward the triptane vertex until 20-percent triptane has been added results in a blend having a rating of 118/145. The addition of 20-percent triptane to the base blend has thus increased the lean rating of the base blend by 8 performance numbers and the rich rating by 22.

On the other hand, if in figure 7 (e) 20-percent benzene is added to the same base blend used in the foregoing example, then the rating changes from 110/123 to 106/146. The addition of 20-percent benzene has decreased the lean rating by 4 performance numbers, whereas the rich rating has been increased by 23.

From this comparison, it follows that in the illustrative example the aromatic (benzene) and the paraffin (triptane) are equally effective for increasing the F-4 (rich) performance

but that triptane is more effective than benzene for improving lean performance.

When any two of the charts in figure 7 or 8 are compared, the nearer a given constant performance line is to the base of the triangle, the better the performance of the fuel represented by the top vertex of the triangle. For example, in figure 7 (a) the line representing an F-4 performance number of 200 is much nearer the base of the triangle than the same line in figure 7 (b). Triptane plus 4 ml TEL per gallon has therefore a higher rating than diisopropyl plus 4 ml TEL per gallon.

Observations similar to those made in the foregoing discussion can be made for the charts in figures 11 and 12. In the case of these figures, however, the effect of a single component cannot be isolated from the other components because the concentration of isopentane varies with that of any other component in the system.

SUMMARY OF RESULTS

Charts are presented that permit the estimation of F-3 and F-4 knock-limited performance ratings for certain ternary and quaternary fuel blends. Ratings for various ternary and quaternary blends estimated from these charts compare favorably with experimental F-3 and F-4 ratings. Because of the unusual behavior of some of the aromatic blends in the F-3 engine, the charts for aromatic-paraffinic blends are probably less accurate than the charts for purely paraffinic blends.

Aircraft Engine Research Laboratory,
  National Advisory Committee for Aeronautics,
    Cleveland, Ohio, January 29, 1945.

APPENDIX

USE OF TRIANGULAR COORDINATE PAPER

The use of triangular coordinate paper to represent composition for a three-component system will be greatly simplified if it is remembered that for any point in an equilateral triangle the sum of the perpendiculars from that point to each of the sides is equal to the altitude of the triangle. For example, in the following diagram $OP+OM+ON=Bb$.
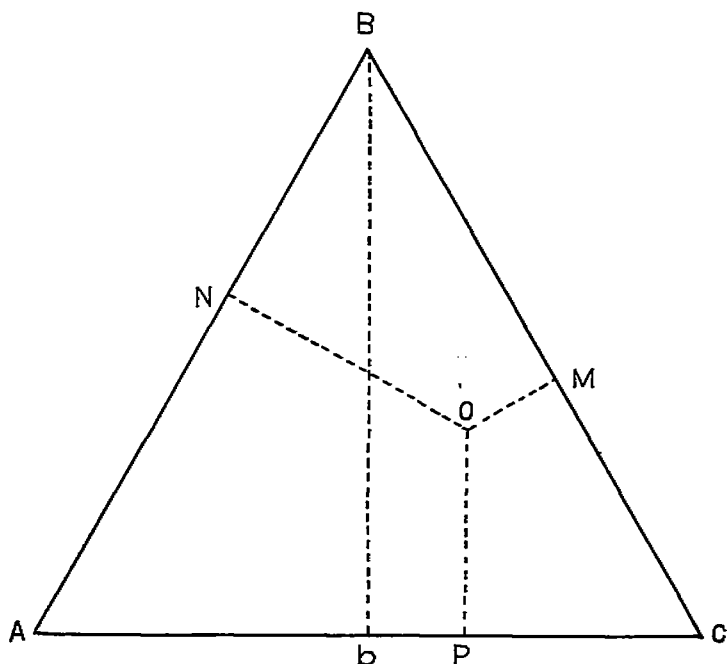
If each of the vertexes of the triangle represent 100 percent of one of the three constituents, then the percentage of component A in blend O is OM, the percentage of the component B is OP, and the percentage of component C is ON.

The equation of a straight line on triangular coordinate paper is of the form

$$a=bN_1+cN_2+N_3$$

where

a, b, c constants

N_1, N_2, N_3 concentration of components 1, 2, and 3 in ternary blend

Any equation relating knock-limited performance and blend composition that can be reduced to this form can be represented by a straight line of constant performance on triangular coordinate paper. Equation (1) presented in the text of this report can be reduced to this form by multiplying through by any one of the performance values $(imep)_1$, $(imep)_2$, or $(imep)_3$.

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4. Sanders, Newell D., Hensley, Reece V., and Breitwieser, Roland: Experimental Studies of the Knock-Limited Blending Characteristics of Aviation Fuels. I—Preliminary Tests in an Air-Cooled Cylinder. NACA ARR No. E4I28, 1944.
5. Wear, Jerrold D., and Sanders, Newell D.: Experimental Studies of the Knock-Limited Blending Characteristics of Aviation Fuels. II—Investigation of Leaded Paraffinic Fuels in an Air-Cooled Cylinder. NACA TN No. 1374, 1947.

TABLE I—PERFORMANCE RATINGS OBTAINED IN F-3 AND F-4 ENGINES

[For each fuel there are three rows of values: The first row is imep, lb/sq in.; the second row for F-3 ratings is octane number or tetraethyl lead in S-3 reference fuel, ml/gal; the second row for F-4 ratings is percentage S-3 reference fuel in M-4 reference fuel or tetraethyl lead in S-3 reference fuel, ml/gal; the third row is performance number. The following abbreviations are used throughout the table: VBS for virgin base stock; alkylate for aviation alkylate; one-pass stock for one-pass catalytic stock; and MTB ether for methyl *tert*-butyl ether.]

Fuel	Fuel composition [a] (by volume)	F-3 ratings	0.065	0.070	0.085	0.095	0.100	0.110
A-355	VBS		73	83	122	137	141	143
		90.7	96.6	99.8	0.08	99.8	99.0	97.8
		75	91	99	103	99	97	94
A-118	50% alkylate+50% VBS		86	99	143	159	162	165
		98.8	0.10	0.19	0.34	0.33	0.29	0.24
		96	104	107	111	111	110	109
A-356	Alkylate		104	129	176	190	195	201
		0.64	0.55	0.93	1.57	1.71	1.87	2.14
		119	117	124	134	135	137	140
A-132	30% one-pass stock+70% VBS		72	71	116	130	136	145
		90.6	93.8	90.0	100	98.0	97.5	97.7
		75	84	78	100	94	94	94
A-116	50% one-pass stock+50% VBS		64	76	116	137	145	156
		90.9	88.6	93.1	100	0.01	0.01	0.06
		76	76	84	100	101	101	103
A-119	80% one-pass stock+20% VBS		67	76	114	142	154	165
		92.7	90.6	93.1	99.2	0.09	0.16	0.24
		79	78	84	97	104	106	109
A-122	30% one-pass stock+70% alkylate		82	103	152	172	178	182
		0.15	100	0.26	0.45	0.58	0.75	0.83
		106	100	110	114	117	121	123
A-117	50% one-pass stock+50% alkylate		76	91	143	167	176	186
		100	96.8	0.06	0.34	0.44	0.58	1.17
		100	91	103	111	114	117	129
A-121	80% one-pass stock+20% alkylate		72	79	123	149	160	177
		96.3	93.8	95	0.09	0.19	0.26	0.48
		88	84	96	104	107	110	115
A-410	One-pass stock		73	83	125	151	164	179
		93.4	96.6	99.8	0.12	0.16	0.28	0.49
		81	91	99	105	106	110	115
A-136	20% triptane+80% VBS		74	90	134	155	162	167
		94.2	95.0	0.05	0.23	0.27	0.27	0.28
		83	88	102	108	110	110	110
A-137	40% triptane+60% VBS		100	119	164	191	201	205
		0.18	0.43	0.55	0.96	1.75	2.07	2.07
		107	114	117	125	136	139	139
A-138	60% triptane+40% VBS		117	142	224	260	264	269
		0.67	1.20	1.58	5.54	----	----	----
		120	129	134	160	175	175	175
A-272	20% triptane+80% alkylate		90	126	185	213	225	237
		1.08	0.19	0.88	2.18	3.17	3.79	4.57
		127	106	123	140	148	152	156
A-273	40% triptane+60% alkylate		98	126	225	262	274	283
		2.43	0.38	0.88	5.69	----	----	----
		142	113	123	160	177	182	184
A-274	60% triptane+40% alkylate		111	159	275	316	326	334
		2.70	0.90	2.76	----	195	213	218
		145	124	145	----	----	----	----
A-275	80% triptane+20% alkylate		139	190	314	----	----	----
		3.06	2.59	5.90	----	----	----	----
		147	144	161	----	----	----	----
A-276	20% triptane+80% one-pass stock [c]		66	72	117	146	160	186
		98.8	90.0	90.7	0.01	0.14	0.26	1.17
		96	77	78	101	105	110	135
A-277	40% triptane+60% one-pass stock [c]		81	89	139	176	195	231
		0.08	99.4	0.05	0.29	0.88	1.77	3.86
		103	99	101	111	124	136	152
A-278	60% triptane+40% one-pass stock [c]		100	109	171	218	244	291
		0.48	0.43	0.36	1.36	3.52	----	----
		115	114	113	131	150	162	190
A-279	80% triptane+20% one-pass stock [c]		126	147	200	361	391	----
		1.80	1.63	1.82	----	----	----	----
		130	134	137	----	----	----	----
A-271	Triptane [c]		191	204	262	[d]393	----	----
		3.30						
		149						
A-397	20% diisopropyl+80% VBS		77	91	132	149	154	155
		96.6	96.9	91	0.20	0.19	0.16	0.04
		90	91	103	108	107	106	101
A-398	40% diisopropyl+60% VBS		81	96	143	167	175	180
		0.09	99.4	0.16	0.34	0.44	0.50	0.67
		103	98	106	112	114	116	120
A-399	60% diisopropyl+40% VBS		96	108	163	187	197	207
		0.33	0.33	0.34	0.90	1.55	1.86	2.21
		111	111	112	124	134	137	141
A-400	80% diisopropyl+20% VBS		111	141	202	226	236	250
		1.17	1.10	1.56	3.23	4.14	5.07	----
		128	127	134	148	153	158	163
A-405	20% diisopropyl+80% alkylate		125	146	192	210	217	222
		0.90	1.78	1.78	2.58	2.97	3.21	3.24
		124	136	136	144	146	148	148
A-406	40% diisopropyl+60% alkylate		138	158	206	227	234	240
		1.45	2.47	2.67	3.49	4.29	4.80	5.00
		132	143	144	150	154	156	157
A-407	60% diisopropyl+40% alkylate		132	154	212	232	262	263
		1.40	1.91	2.29	3.87	----	----	----
		132	138	141	152	162	167	171
A-408	80% diisopropyl+20% alkylate		136	162	226	261	275	292
		2.10	2.24	3.05	5.85	----	----	----
		139	141	147	161	176	182	190
A-401	20% diisopropyl+80% one-pass stock		79	89	132	163	177	195
		96.1	98.1	0.05	0.20	0.39	0.67	1.60
		88	95	102	108	113	120	134
A-402	40% diisopropyl+60% one-pass stock		84	99	150	177	189	209
		0.06	0.05	0.20	0.43	0.95	1.48	2.34
		102	102	108	114	125	133	142

Fuel	Fuel composition [a] (by volume)	F-3 ratings	0.065	0.070	0.085	0.095	0.100	0.110
A-403	60% diisopropyl+40% one-pass stock		96	114	165	196	210	235
		0.24	0.33	0.44	1.02	2.00	2.72	4.29
		108	111	114	126	138	145	154
A-404	80% diisopropyl+20% one-pass stock		120	143	197	229	246	272
		0.68	1.34	1.05	2.90	4.57	----	----
		120	131	135	146	155	162	177
A-393	Diisopropyl [e]		147	178	216	259	304	324
		2.41	3.53	4.11	----	----	----	----
		142	150	158	175	195	----	----
A-411	20% neohexane+80% VBS		74	86	124	142	147	150
		94.5	95.0	100	0.10	0.09	0.05	99.2
		84	88	100	104	103	102	98
A-412	40% neohexane+60% VBS		81	97	138	158	164	167
		0.05	99.4	0.17	0.28	0.31	0.32	0.28
		102	98	106	110	111	111	110
A-413	60% neohexane+40% VBS		93	108	159	179	183	187
		0.36	0.26	0.34	0.67	1.03	1.17	1.25
		112	110	112	120	126	128	130
A-414	80% neohexane+20% VBS		108	130	182	203	208	210
		2.00	0.75	1.06	1.95	2.48	2.57	2.41
		138	121	127	138	143	143	142
A-415	20% neohexane+80% alkylate		112	130	172	193	199	202
		1.10	0.95	1.06	1.41	1.85	1.95	1.91
		127	125	127	132	137	138	138
A-416	40% neohexane+60% alkylate		118	137	186	203	207	209
		1.50	1.25	1.38	2.19	2.48	2.50	2.35
		133	130	131	140	143	143	142
A-417	60% neohexane+40% alkylate		124	146	195	212	215	216
		2.57	1.53	1.73	2.73	3.10	3.07	2.83
		143	133	136	145	147	147	145
A-418	80% neohexane+20% alkylate		137	158	205	224	227	226
		3.36	2.35	2.67	3.61	3.93	3.93	3.52
		149	142	144	151	152	152	150
A-420	20% neohexane+80% one-pass stock		79	95	146	171	180	190
		96.6	98.1	0.14	0.35	0.50	0.92	1.38
		90	95	105	113	116	124	131
A-421	40% neohexane+60% one-pass stock		86	107	165	190	197	203
		0.10	0.10	0.33	1.02	1.70	1.86	1.96
		104	104	111	126	135	137	138
A-422	60% neohexane+40% one-pass stock		108	138	192	210	215	217
		0.33	0.75	1.43	2.58	2.97	3.07	2.90
		111	121	132	143	146	147	146
A-423	80% neohexane+20% one-pass stock		132	162	214	230	233	234
		1.66	1.91	3.05	4.00	4.72	4.57	4.14
		135	138	147	153	156	156	153
A-394	Neohexane [f]		159	187	230	240	242	243
		6.00	4.76	5.58	----	----	5.87	5.43
		161	156	160	163	162	161	159
A-123	20% isopentane+80% VBS		72	87	127	141	146	149
		94.4	93.8	0.02	0.14	0.07	0.03	98.9
		83	84	101	106	103	101	99
A-124	40% isopentane+60% VBS		80	99	139	151	155	159
		99.1	98.8	0.20	0.29	0.21	0.18	0.12
		97	96	108	110	108	107	105
A-134	60% isopentane+40% VBS		87	112	153	168	172	174
		0.23	0.12	0.41	0.46	0.46	0.45	0.42
		108	105	114	114	114	114	113
A-375	20% isopentane+80% alkylate		121	144	186	201	204	204
		0.92	1.39	1.69	2.19	2.34	2.29	2.00
		124	131	135	140	142	141	138
A-376	40% isopentane+60% alkylate		121	144	191	203	205	204
		0.99	1.39	1.69	2.52	2.48	2.36	2.00
		125	131	135	143	143	142	138
A-388	20% isopentane+80% one-pass stock		78	87	132	160	173	182
		95.8	97.5	0.02	0.20	0.34	0.47	1.29
		87	94	101	108	111	115	130
A-389	40% isopentane+60% one-pass stock		85	97	140	168	180	202
		100	0.07	0.17	0.30	0.46	0.92	1.47
		100	103	107	111	115	124	133
A-139	20% hot-acid octane+80% VBS		70	83	128	147	151	154
		94.3	92.5	98.0	0.15	0.16	0.11	0.02
		83	88	94	106	106	105	101
A-140	40% hot-acid octane+60% VBS		74	89	143	168	173	179
		100	95.0	0.03	0.34	0.46	0.47	0.58
		100	94	101	111	114	115	117
A-141	60% hot-acid octane+40% VBS		84	106	165	191	198	207
		0.18	0.05	0.31	1.02	1.75	1.91	2.21
		107	102	111	126	136	138	140
A-367	20% hot-acid octane+80% alkylate		121	142	188	205	210	215
		0.82	1.39	1.60	2.32	2.62	2.73	2.76
		123	131	134	141	144	145	145
A-368	40% hot-acid octane+60% alkylate		125	148	200	219	226	235
		0.72	1.58	1.87	3.10	3.59	3.96	4.29
		121	134	137	147	150	152	154
A-369	60% hot-acid octane+40% alkylate		129	154	216	240	248	257
		0.88	1.77	2.29	4.31	----	----	----
		124	136	141	154	162	164	168
A-370	80% hot-acid octane+20% alkylate		129	154	238	269	276	250
		0.72	1.77	2.29	----	----	----	----
		121	136	141	169	182	183	182
A-371	20% hot-acid octane+80% one-pass stock		80	90	128	170	185	205
		95.1	98.8	0.06	0.28	0.49	1.30	2.14
		86	95	102	110	115	130	142
A-372	40% hot-acid octane+60% one-pass stock		84	97	154	192	208	229
		100	0.14	0.17	0.48	1.80	2.57	3.73
		100	105	107	115	136	143	151

[a] Each fuel contains approximately 4 ml TEL/gal.
[b] Based on fixed reference-fuel framework (reference 1).
[c] Knock-limited performance of engine with one-pass catalytic stock was low on day fuels were investigated.
[d] Estimated value.
[e] Values for knock-limited imep were averaged from three curves.
[f] Values for knock-limited imep were averaged from two curves.

TABLE I—PERFORMANCE RATINGS OBTAINED IN F-3 AND F-4 ENGINES—Concluded

Fuel	Fuel composition [a] (by volume)	F-3 ratings	F-4 ratings [b] Fuel-air ratio					
			0.065	0.070	0.085	0.095	0.100	0.110
A-373	60% hot-acid octane+40% one-pass stock	---- / 0.18 / 107	90 / 0.19 / 107	101 / 0.23 / 108	164 / 0.96 / 126	203 / 2.48 / 142	220 / 3.43 / 149	245 / 5.71 / 160
A-374	80% hot-acid octane+20% one-pass stock	---- / 0.45 / 115	99 / 0.41 / 114	115 / 0.45 / 115	187 / 2.26 / 141	224 / 3.93 / 152	240 / 5.60 / 160	268 / ---- / 175
A-330	Hot-acid octane [f]	1.08 / 127	131 / 1.86 / 137	159 / 2.76 / 145	250 / --- / 178	289 / --- / 195	304 / --- / ---	317 / --- / ---
A-257	20% mixed xylenes+80% VBS	---- / 92.6 / 79	68 / 91.3 / 79	78 / 94.7 / 86	114 / 99.2 / 97	132 / 98.7 / 96	138 / 98.1 / 94	148 / 98.6 / 96
A-258	40% mixed xylenes+60% VBS	---- / 95.5 / 86	69 / 91.9 / 80	78 / 94.7 / 86	117 / 0.16 / 101	147 / 0.16 / 106	160 / 0.26 / 110	182 / 0.83 / 123
A-259	60% mixed xylenes+40% VBS	---- / 95.2 / 86	74 / 95.0 / 87	85 / 99.3 / 99	146 / 0.38 / 113	194 / 1.90 / 137	216 / 3.14 / 148	253 / ---- / 165
A-260	80% mixed xylenes+20% VBS	---- / 0.04 / 101	84 / 0.05 / 102	95 / 0.14 / 105	214 / 4.00 / 153	---- / --- / ---	---- / --- / ---	---- / --- / ---
A-261	20% mixed xylenes+80% alkylate	---- / 0.52 / 116	88 / 0.14 / 105	101 / 0.28 / 108	158 / 0.65 / 119	194 / 1.90 / 137	208 / 2.57 / 143	227 / 3.59 / 150
A-262	40% mixed xylenes+60% alkylate	---- / 0.27 / 110	92 / 100 / 100	95 / 0.14 / 105	153 / 0.46 / 115	206 / 2.69 / 144	252 / ---- / 167	257 / ---- / 187
A-263	60% mixed xylenes+40% alkylate	---- / 0.14 / 105	85 / 0.07 / 103	98 / 0.19 / 107	181 / 1.89 / 137	274 / ---- / 185	---- / --- / ---	---- / --- / ---
A-264	80% mixed xylenes+20% alkylate	---- / 0.27 / 110	87 / 0.12 / 105	103 / 0.27 / 110	260 / --- / 185	336 / --- / ---	370 / --- / ---	---- / --- / ---
A-265	20% mixed xylenes+80% one-pass stock [e]	---- / 94.7 / 84	71 / 93.1 / 83	74 / 92.0 / 81	111 / 97.9 / 94	138 / 0.03 / 101	151 / 0.11 / 105	178 / 0.50 / 116
A-266	40% mixed xylenes+60% one-pass stock [e]	---- / 97.5 / 92	80 / 98.8 / 95	86 / 100 / 100	133 / 0.21 / 108	172 / 0.58 / 118	196 / 1.81 / 136	246 / 5.86 / 161
A-267	60% mixed xylenes+40% one-pass stock [e]	---- / 98.8 / 96	95 / 0.31 / 111	100 / 0.22 / 108	184 / 2.06 / 139	251 / ---- / 169	282 / 187 / ---	339 / ---- / ---
A-268	80% mixed xylenes+20% one-pass stock [e]	0.16 / 106	102 / 0.48 / 115	105 / 0.31 / 111	351 / --- / ---	---- / --- / ---	---- / --- / ---	---- / --- / ---
A-256	Mixed xylenes [e]	---- / 0.92 / 124	105 / 0.60 / 118	122 / 0.69 / 120	---- / --- / ---	---- / --- / ---	---- / --- / ---	---- / --- / ---
A-245	20% cumene+80% VBS	---- / 92.4 / 78	67 / 90.6 / 78	72 / 90.7 / 78	98 / 92.5 / 82	123 / 95.7 / 88	134 / 96.9 / 91	154 / 0.02 / 101
A-244	40% cumene+60% VBS	---- / 92.7 / 79	67 / 90.6 / 78	70 / 89.3 / 78	95 / 91.3 / 80	117 / 93.7 / 84	130 / 96.6 / 88	160 / 0.14 / 105
A-246	60% cumene+40% VBS	---- / 94.2 / 83	67 / 90.6 / 78	72 / 90.7 / 78	94 / 90.8 / 78	118 / 94.0 / 85	132 / 96.3 / 91	174 / 0.42 / 114
A-247	80% cumene+20% VBS	---- / 96.0 / 88	77 / 96.9 / 91	76 / 93.3 / 84	90 / 89.2 / 76	120 / 94.7 / 86	151 / 0.11 / 105	---- / --- / ---
A-248	20% cumene+80% alkylate	---- / 0.32 / 111	98 / 0.38 / 113	102 / 0.25 / 109	143 / 0.34 / 111	172 / 0.58 / 117	187 / 1.39 / 131	215 / 2.76 / 145
A-249	40% cumene+60% alkylate	---- / 0.11 / 105	71 / 93.1 / 84	76 / 93.3 / 84	113 / 98.8 / 95	148 / 0.17 / 106	171 / 0.44 / 114	233 / 4.00 / 153
A-250	60% cumene+40% alkylate	---- / 0.03 / 101	77 / 96.9 / 91	76 / 93.3 / 84	94 / 90.8 / 78	124 / 96.0 / 90	149 / 0.08 / 103	277 / 150 / ---
A-251	80% cumene+20% alkylate	---- / 97.7 / 93	74 / 95.0 / 87	73 / 91.3 / 80	86 / 87.5 / 78	114 / 92.7 / 82	160 / 0.25 / 110	---- / --- / ---
A-252	20% cumene+80% one-pass stock	---- / 93.0 / 80	70 / 92.5 / 82	69 / 88.6 / 75	91 / 89.6 / 76	120 / 94.3 / 85	137 / 97.8 / 93	175 / 0.44 / 114
A-253	40% cumene+60% one-pass stock	---- / 93.6 / 82	70 / 92.5 / 82	67 / 87.4 / 74	75 / 82.9 / 67	95 / 86.3 / 72	112 / 90.0 / 77	168 / 0.30 / 111
A-254	60% cumene+40% one-pass stock	---- / 93.0 / 80	66 / 90.0 / 78	62 / 84.0 / 68	65 / 78.8 / 62	81 / 81.3 / 65	94 / 84.4 / 69	153 / 100 / 100
A-255	80% cumene+20% one-pass stock	---- / 95.0 / 85	66 / 90.0 / 78	66 / 84.8 / 69	70 / 80.8 / 64	98 / 87.3 / 74	141 / 99.1 / 98	---- / --- / ---
A-240	Cumene [e]	---- / 95.0 / 85	77 / 96.9 / 91	75 / 92.7 / 83	87 / 87.9 / 74	122 / 95.3 / 88	---- / --- / ---	---- / --- / ---
A-341	20% benzene+80% VBS	---- / 91.4 / 76	78 / 97.5 / 93	85 / 99.4 / 97	134 / 0.22 / 108	155 / 0.27 / 110	162 / 0.29 / 110	168 / 0.30 / 111
A-342	40% benzene+60% VBS	---- / 92.4 / 78	81 / 99.4 / 97	89 / 0.05 / 102	146 / 0.37 / 112	178 / 1.03 / 128	190 / 1.63 / 134	208 / 2.28 / 141
A-343	60% benzene+40% VBS	---- / 94.2 / 83	78 / 97.5 / 93	85 / 99.4 / 97	244 / 173 / ---	346 / --- / ---	384 / --- / ---	---- / --- / ---
A-344	80% benzene+20% VBS	---- / 96.2 / 88	98 / 0.38 / 113	115 / 0.45 / 115	---- / --- / ---	---- / --- / ---	---- / --- / ---	---- / --- / ---
A-358	20% benzene+80% alkylate	---- / 0.43 / 114	117 / 1.20 / 129	127 / 0.92 / 124	182 / 1.95 / 187	212 / 3.10 / 147	222 / 3.57 / 150	234 / 4.14 / 153

Fuel	Fuel composition [a] (by volume)	F-3 ratings	F-4 ratings [b] Fuel-air ratio					
			0.065	0.070	0.085	0.095	0.100	0.110
A-359	40% benzene+60% alkylate	---- / 0.12 / 105	102 / 0.48 / 115	112 / 0.41 / 114	182 / 1.95 / 137	230 / 4.72 / 156	253 / ---- / 168	295 / ---- / 192
A-360	60% benzene+40% alkylate	---- / 100 / 100	102 / 0.48 / 115	110 / 0.38 / 113	336 / --- / ---	---- / --- / ---	---- / --- / ---	---- / --- / ---
A-361	80% benzene+20% alkylate	---- / 98.3 / 94	119 / 1.30 / 130	178 / 4.63 / 156	---- / --- / ---	---- / --- / ---	---- / --- / ---	---- / --- / ---
A-362	20% benzene+80% one-pass stock	---- / 93.8 / 82	77 / 96.9 / 91	86 / 100 / 100	142 / 0.33 / 111	172 / 0.58 / 118	184 / 1.25 / 130	203 / 1.96 / 138
A-363	40% benzene+60% one-pass stock	---- / 92.0 / 78	82 / 100 / 100	79 / 95.3 / 88	160 / 0.73 / 121	213 / 3.17 / 148	238 / 5.33 / 159	264 / ---- / 172
A-364	60% benzene+40% one-pass stock	---- / 91.5 / 77	68 / 91.3 / 80	72 / 90.7 / 78	191 / 2.52 / 143	254 / ---- / 172	280 / ---- / 186	328 / ---- / ---
A-365	80% benzene+20% one-pass stock	---- / 93.0 / 80	94 / 0.29 / 110	93 / 0.11 / 105	---- / --- / ---	---- / --- / ---	---- / --- / ---	---- / --- / ---
A-340	Benzene [f]	--- / 87 / 68	199 / 156	--- / 196	---	---	---	---
A-321	20% toluene+80% VBS	---- / 93.7 / 82	85 / 0.07 / 103	96 / 0.16 / 106	137 / 0.26 / 110	156 / 0.29 / 110	164 / 0.32 / 111	172 / 0.27 / 110
A-322	40% toluene+60% VBS	---- / 95.1 / 85	92 / 0.24 / 109	96 / 0.16 / 106	175 / 1.57 / 134	228 / 4.43 / 155	245 / ---- / 162	266 / ---- / 173
A-323	60% toluene+40% VBS	---- / 97.0 / 91	88 / 0.14 / 105	95 / 0.14 / 105	204 / 3.36 / 149	303 / ---- / ---	346 / ---- / ---	425 / ---- / ---
A-324	80% toluene+20% VBS	---- / 98.8 / 96	101 / 0.45 / 115	113 / 0.42 / 114	340 / --- / ---	---- / --- / ---	---- / --- / ---	---- / --- / ---
A-325	20% toluene+80% alkylate	---- / 0.48 / 115	121 / 1.39 / 131	139 / 1.47 / 132	191 / 2.52 / 143	221 / 3.73 / 151	232 / 4.53 / 155	249 / ---- / 162
A-326	40% toluene+60% alkylate	---- / 0.54 / 116	108 / 0.75 / 121	128 / 0.97 / 125	223 / 5.38 / 159	275 / ---- / 186	308 / --- / ---	348 / --- / ---
A-327	60% toluene+40% alkylate	---- / 0.25 / 109	100 / 0.43 / 114	106 / 0.30 / 111	300 / --- / ---	---- / --- / ---	---- / --- / ---	---- / --- / ---
A-328	80% toluene+20% alkylate	---- / 0.16 / 106	108 / 0.75 / 121	116 / 0.47 / 115	---- / --- / ---	---- / --- / ---	---- / --- / ---	---- / --- / ---
A-331	20% toluene+80% one-pass stock	---- / 95.1 / 85	80 / 98.8 / 95	90 / 0.06 / 103	137 / 0.25 / 110	169 / 0.47 / 115	184 / 1.25 / 130	212 / 2.55 / 143
A-332	40% toluene+60% one-pass stock	---- / 95.3 / 86	85 / 0.07 / 103	92 / 0.09 / 103	151 / 0.44 / 114	202 / 2.41 / 142	224 / 3.72 / 151	262 / ---- / 171
A-333	60% toluene+40% one-pass stock	---- / 97.4 / 91	91 / 0.21 / 108	95 / 0.14 / 105	178 / 1.73 / 135	270 / ---- / 182	319 / ---- / ---	---- / --- / ---
A-334	80% toluene+20% one-pass stock	---- / 0.10 / 104	102 / 0.48 / 115	106 / 0.31 / 111	---- / --- / ---	---- / --- / ---	---- / --- / ---	---- / --- / ---
A-320	Toluene [f]	---- / 0.57 / 118	134 / 2.00 / 138	140 / 1.51 / 133	---- / --- / ---	---- / --- / ---	---- / --- / ---	---- / --- / ---
A-336	20% MTB ether+80% VBS	---- / 98.8 / 96	95 / 0.31 / 111	101 / 0.23 / 108	144 / 0.30 / 111	170 / 0.49 / 115	179 / 0.83 / 121	187 / 1.25 / 130
A-337	40% MTB ether+60% VBS	---- / 0.12 / 105	112 / 0.95 / 125	113 / 0.42 / 114	165 / 1.02 / 126	204 / 2.55 / 143	223 / 3.64 / 151	253 / ---- / 165
A-338	60% MTB ether+40% VBS	---- / 0.92 / 124	192 / ---- / 180	---- / 3.14 / 148	228 / ---- / 162	281 / ---- / 190	307 / --- / ---	355 / --- / ---
A-339	80% MTB ether+20% VBS	---- / 2.61 / 144	---- / --- / ---	---- / --- / ---	239 / --- / ---	309 / --- / ---	379 / --- / ---	---- / --- / ---
A-347	20% MTB ether+80% alkylate	---- / 1.68 / 135	143 / 3.06 / 146	155 / 2.38 / 142	230 / 163 / ---	258 / 174 / ---	268 / 178 / ---	281 / 183 / ---
A-348	40% MTB ether+60% alkylate	---- / 2.30 / 141	166 / 5.43 / 159	174 / 4.21 / 154	258 / 183 / ---	312 / ---- / ---	338 / ---- / ---	377 / ---- / ---
A-349	60% MTB ether+40% alkylate	---- / 2.50 / 143	258 / ---- / ---	229 / ---- / 198	327 / 183 / ---	406 / ---- / ---	442 / ---- / ---	---- / --- / ---
A-350	80% MTB ether+20% alkylate	---- / 6.0 / 161	307 / --- / ---	271 / 198 / ---	374 / --- / ---	---- / --- / ---	---- / --- / ---	---- / --- / ---
A-351	20% MTB ether+80% one-pass stock	---- / 96.1 / 88	87 / 0.12 / 105	91 / 0.08 / 103	144 / 0.35 / 112	179 / 1.10 / 127	194 / 1.72 / 135	213 / 2.07 / 146
A-352	40% MTB ether+60% one-pass stock	---- / 0.14 / 105	113 / 1.00 / 126	112 / 0.41 / 114	163 / 0.85 / 123	204 / 2.55 / 143	225 / 3.79 / 152	269 / ---- / 175
A-353	60% MTB ether+40% one-pass stock	---- / 0.47 / 115	185 / ---- / 173	160 / 2.86 / 146	230 / 163 / ---	289 / 195 / ---	319 / ---- / ---	376 / ---- / ---
A-354	80% MTB ether+20% one-pass stock	---- / 1.00 / 126	269 / ---- / ---	237 / 200 / ---	301 / --- / ---	370 / --- / ---	---- / --- / ---	---- / --- / ---
A-335	MTB ether [f]	>6.00 / >161	---- / --- / ---	---- / 330 / ---	---- / 406 / ---	---- / --- / ---	---- / --- / ---	---- / --- / ---

TABLE II—F-3 AND F-4 PERFORMANCE RATINGS AND REID VAPOR PRESSURES FOR VARIOUS AVIATION-FUEL COMPONENTS

Blending agent	Reid vapor pressure (lb/sq in.)	Performance number [a]		Blending agent	Reid vapor pressure (lb/sq in.)	Performance number [a]	
		F-3	F-4 [b]			F-3	F-4 [b]
Isopentane	19.6	[c] 133	[c] 144	Benzene	1.5	[d] 68	>200
Neohexane	8.7	161	159	Triptane	3.0	149	>200
Methyl tert-butyl ether	8.8	>161	>200	Hot-acid octane	2.7	127	197
Diisopropyl	7.4	142	202	Toluene	1.1	118	>200
Virgin base stock	5.9	73	94	Mixed xylenes	.5	124	>200
Alkylate	4.7	119	137	Cumene	.3	85	>200

[a] Performance numbers are for pure blending agent containing 4 ml TEL/gal.
[b] Performance numbers over 161 are extrapolated (fig. 1). Ratings are for fuel-air ratio of 0.11.
[c] Extrapolated from experimental data for blends containing up to 60-percent isopentane.
[d] Assumed to be same as rating for unleaded benzene.

TABLE III—F-3 AND F-4 PERFORMANCE RATINGS OF TERNARY AND QUATERNARY FUEL BLENDS

[The following abbreviations are used throughout the table: VBS for virgin base stock; alkylate for aviation alkylate; one-pass stock for one-pass catalytic stock; and MTB ether for methyl tert-butyl ether.]

Figure	Fuel	Fuel composition [a] (by volume)	F-3 ratings		F-4 ratings [b]		Figure	Fuel	Fuel composition [a] (by volume)	F-3 ratings		F-4 ratings [b]	
			Estimated	Observed	Estimated	Observed				Estimated	Observed	Estimated	Observed
Ternary blends							Ternary blends—Concluded						
6	A-477	59% hot-acid octane+25% VBS+16% alkylate	112	110	150	149	7 (h)	A-521	23% toluene+17% VBS+60% alkylate	107	106	160	156
6	A-487	11% hot-acid octane+48% VBS+41% alkylate	98	90	110	111	7 (i)	A-520	33% MTB ether+55% VBS+12% alkylate	106	108	160	154
7 (a)	A-233	20% triptane+6% VBS+74% alkylate	126	126	150	151	7 (i)	A-539	6% MTB ether+59% VBS+35% alkylate	94	99	110	111
7 (a)	A-235	29% triptane+20% VBS+51% alkylate	119	120	150	151	8 (a)	A-470	55% hot-acid octane+13% one-pass stock+32% alkylate	118	118	160	159
7 (a)	A-234	38% triptane+35% VBS+27% alkylate	114	115	150	150	8 (b)	A-471	35% triptane+45% one-pass stock+20% alkylate	108	111	160	159
7 (a)	A-466	43% triptane+28% VBS+29% alkylate	119	116	160	158	8 (b)	A-480	20% triptane+16% one-pass stock+64% alkylate	117	112	150	150
7 (a)	A-481	12% triptane+14% VBS+74% alkylate	116	117	140	142	8 (c)	A-555	39% diisopropyl+24% one-pass stock+37% alkylate	118	115	150	150
7 (a)	A-486	13% triptane+61% VBS+26% alkylate	95	93	110	112							
7 (b)	A-478	43% diisopropyl+12% VBS+45% alkylate	123	122	150	150							
7 (b)	A-524	34% diisopropyl+52% VBS+14% alkylate	103	101	120	121	Quaternary blends						
7 (c)	A-483	56% neohexane+14% VBS+30% alkylate	131	124	140	140	12 (a)	A-472	19% triptane+10% hot-acid octane+52.5% alkylate+18.5% isopentane	128	131	160	157
7 (c)	A-523	12% neohexane+43% VBS+45% alkylate	102	103	110	111	12 (b)	A-474	11.5% triptane+25.5% diisopropyl+50.5% alkylate+12.5% isopentane	130	136	160	159
7 (e)	A-482	23% benzene+34% VBS+43% alkylate	97	100	140	139	12 (d)	A-473	34% diisopropyl+12.5% hot-acid octane+41.5% alkylate+12% isopentane	129	131	159	159
7 (e)	A-522	47% benzene+41% VBS+12% alkylate	87	77	160	154							
7 (h)	A-484	14% toluene+54% VBS+32% alkylate	92	97	130	130							

[a] Each fuel contains approximately 4 ml TEL/gal.
[b] F-4 ratings made at fuel-air ratio of 0.11.